Evaluation of Control System Architecture for a Research Engine

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Bachelor's thesis

Electrical Engineering

Vaasa 2013

BACHELOR'S THESIS
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Degree programme: Electrical Engineering, Vaasa
Specialization: Automation
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Title: *Evaluation of Control System Architecture for a Research Engine*

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15 April 2013 48 pages 5 appendices

Abstract:
This Bachelor's thesis has been done for Wärtsilä Finland Oy during the winter 2012 – 2013. The single cylinder engine test team at the engine laboratory Waskiluoto Validation Centre (WVC) has been my commissioner.

The thesis work is mainly an evaluation of an existing engine control system for a single cylinder research engine. Moreover, it also describes ways of implementing the control system into a new upcoming test engine. Improvement proposals and plans for an upcoming control system have been made, based on the evaluation of the existing system. The background of this evaluation was that another single cylinder test engine (for smaller cylinder bores) will arrive at WVC at the end of 2013. Some research of the existing engine control system was therefore needed before a similar engine control system can be taken into use.

The evaluation has been concentrated on the PLC part of the engine control system. Important factors that have been considered during the evaluation and planning of the new control system were the stability of the system, the costs, the overall control system performance, the serviceability, the interface to other external systems, the cable routing and the total cable lengths. The thesis has resulted in a functional plan of the engine control system, with layouts of the main cabinets and a list of what parts to order.

Language: English Key words: PLC, single cylinder engine, control system, test cell planning

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EXAMENSARBETE

Författare: Markus Nybjörk
Utbildningsprogram och ort: Elektroteknik, Vasa
Inriktningsalternativ: Automation
Handledare: Matts Nickull

Titel: *Utvärdering av arkitekturuuren för ett kontrollsystem till en forskningsmotor*

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15 april 2013 48 sidor 5 bilagor

Abstrakt

Detta examensarbete har gjorts åt Wärtsilä Finland Oy under vintern 2012–2013. Min uppdragsgivare har varit singelcylindertestmotor-gruppen, som finns placerad i motorlaboratoriet Waskiluoto Validation Centre (WVC).

Examensarbetet är till största del en utredning av ett befintligt motorkontrollssystem för en singelcylindertestmotor. Därtill beskriver det också sätt att implementera ett liknande system på en ny kommande testmotor. Förbättringsförslag och planer för det kommande kontrollsystemet har blivit gjorda, baserade på undersökningen av det befintliga kontrollsystemet. Bakgrunden till denna undersökning var att ännu en singelcylindertestmotor (för mindre cylinderdimensioner) kommer att anlända till WVC i slutet av år 2013. En del undersökningar av det befintliga motorkontrollsystemet var därför nödvändiga innan ett liknande system kan tas i bruk.

Undersökningen har koncentrerats till PLC-delen av motorns kontrollsystem. Viktiga faktorer som har beaktats i undersökningen och planeringen av det nya systemet är systemets stabilitet, den totala kostnaden, systemets prestanda, servicevänlighet, kommunikation med andra externa system, kabelrutter och totala kabellängder. Examensarbetet har resulterat i en funktionell plan över det kommande automationssystemet, med översiktsbilder av automationsskåpen samt en beställningslista med komponenter som behövs till dem.

Språk: engelska Nyckelord: PLC, singelcylindermotor, kontroll-system, testcell planering

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Nimike: *Arviointi ohjausjärjestelmäarkkitehtuurista tutkimusmoottorille*

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15 huhtikuu 2013 48 sivut 5 liitteet

Tiivistelmä

Tämä opinnäytetyö on tehty Wärtsilä Finland Oy:lle talvena 2012 - 2013. Minun toimeksiantajani on ollut yksisylinterisen moottorin testausryhmä moottorilaboratoriossa Waskiluoto Validation Centressä (WVC).

Opinnäytetyö on pääosin arvio olemassa olevasta moottoriohjausjärjestelmästä yksisylinteriseen tutkimusmoottoriin. Sen lisäksi, työ kuvailee, miten saada samanlainen ohjausjärjestelmä toimimaan tulevalla tutkimusmoottorilla. Parannusehdotuksia ja suunnitelmia tulevaan ohjausjärjestelmään on tehty tämän tutkimuksen avulla. Opinnäytetyön tausta oli, että uusi yksisylinterinen tutkimusmoottori (pienemmälle sylinterihalkaisijalle) saapuu WVC:lle vuoden 2013 lopussa. Nykyisen moottorin ohjausjärjestelmän analysointi tarvitaan ennen kuin se voidaan jatkokehittää uuteen käyttöön.

Tutkimus on keskittynyt PLC-osaan moottoriohjausjärjestelmästä. Tärkeitä asioita uuden järjestelmän suunnittelussa on ollut luotettavuus, kulut, suorituskyky, huoltoystävällisyys, muiden järjestelmien kommunikaatio, kaapelointi ja niiden pituus. Opinnäytetyön tulos on toimiva ratkaisu tuleviin automaatiojärjestelmiin. Sen lisäksi on tehty pääkaavioita automaatiokaapeista sekä tilauslistoja niiden komponenteista.

Kieli: englanti Avainsanat: PLC, yksisylinterinen testausmoottori, ohjausjärjestelmä, testisolun suunnittelu

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Abbreviations

AI	= Analogue Input
AO	= Analogue Output
CB	= Connection Box
CCM-20	= Cylinder Control Module 20
CEO	= Chief Executive Officer
CO	= Carbon monoxide
CO2	= Carbon dioxide
CR	= Common Rail
DF	= Dual Fuel
DH water	= District Heating water
DI	= Digital Input
DO	= Digital Output
EGR	= Exhaust Gas Recirculation
EHVA	= Electrical Hydraulic Valve Actuators
HFO	= Heavy Fuel Oil
HMI	= Human Machine Interface
HT water	= High Temperature water
I/O	= Input/Output
LDU-20	= Local Display Unit 20
LFO	= Light Fuel Oil
LNG	= Liquefied Natural Gas
MCE	= Multi Cylinder Engine
NOx	= Nitrogen oxides (NO and NO2)
O2	= Oxygen
PCB	= Printed Circuit Board
PI schematic	= Piping and Instrumentation schematic
PLC	= Programmable Logic Controller
PTV	= Performance, Testing and Validation
R&D	= Research and Development
SCE	= Single Cylinder Engine
SG	= Spark ignited Gas
SSV	= Stop and Safety Valve
THC	= Total Unburned Hydrocarbons
UPS	= Uninterruptible Power Supply
WVC	= Waskiluoto Validation Centre

Preamble

I want to take the opportunity and thank all the personnel at the Wärtsilä engine laboratory for the help achieved. I also want to give special thanks to my supervisors Mr. Guy Hägglund and Mr. Staffan Nysand at Wärtsilä and Mr. Matts Nickull at Novia University of Applied Sciences.

4 April 2013

Markus Nybjörk

1 Introduction

Wärtsilä Oyj Abp is a global engine manufacture company, with the headquarters located in Helsinki. Wärtsilä develops and produces large combustion engines for the marine market and for power plants, and the main product within their product portfolio is 4-stroke medium sized engines. Wärtsilä offers complete power solutions or just parts of engine concepts. Furthermore, Wärtsilä offers services to engine concepts and peripheral equipment according to the costumers needs. [3]

Wärtsilä was founded in 1834, when a lumber mill was established in Karelia. Almost 100 years after that in 1938, the engine manufacturing began when Wärtsilä signed a licence agreement with Friedrich Krupp Germania Werft AG in Germany. In 1942 Wärtsilä manufactured their first diesel engine, but not until 1960 did they design their own diesel engine, i.e. the type 14. In 1988 a modern engine laboratory was established in Vaasa, which has later been followed by other engine laboratories around the world. As of today Wärtsilä has approximately 18 000 employees located in nearly 170 different locations and 70 different countries. The different business areas that Wärtsilä upholds can be seen in *Figure 1*, where the biggest business area is Services followed by Power Plants and Ship Power, and as of today the CEO of Wärtsilä is Mr Björn Rosengren. [3] [26] [27]

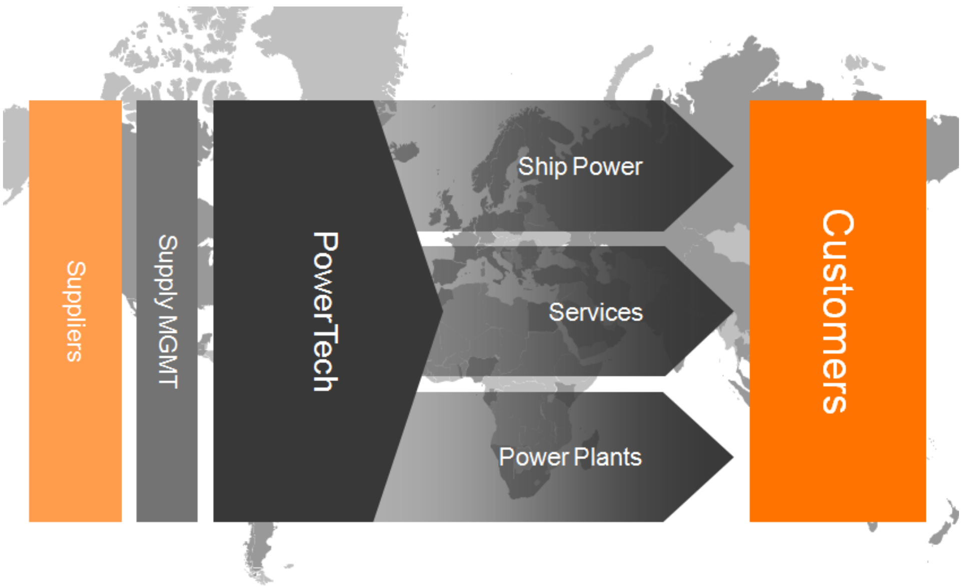

Figure 1. Chart of Wärtsilä Corporation [24]

The three main business areas within Wärtsilä are supported by several support functions, of which PowerTech can be mentioned. PowerTech works on improvements of the quality and the technology for Wärtsilä engines, parts and concepts. Within PowerTech there are several subdivisions. One of those is called Research & Development and manages the research and the development of new products, technologies and concepts, with a strong focus on innovative solutions for 4-stroke engines. To test and validate the different engine concepts, R&D has a department called Performance, Testing and Validation (PTV). To manage the testing and validating, PTV upholds engine laboratories across Europe, with operations in Spain, Italy and Finland. In the laboratories there are several test engines and test rigs which are run and tested by different engine test teams, of which one test team is the Single Cylinder Engine, for which this thesis work has been done. [28]

1.1 General

The thesis work was done during autumn 2012 and finalized at the beginning of 2013. The SCE (Single Cylinder Engine) group is located in the engine laboratory Waskiluoto Validation Centre located in Vaasa. At the time of writing the SCE has one engine that they are responsible for, but the planning for another SCE has already started. The single cylinder engine is actually one of the test engines that isn't manufactured to the end customer. Its purpose is instead to develop the combustion system and strengthen the knowledge of engine behaviour in Wärtsilä Corporation.

1.2 Background for the degree thesis

Because the working procedure with the SCE had proven to be effective (the strengths of a SCE will be explained in chapter 2), Wärtsilä decided to install another SCE in Waskiluoto Validation Centre. This new SCE was planned to arrive during the summer 2013 and would be used to develop the engine portfolio for engines with a bore of 200 mm and possible other bores in the same area in the future. Since the SCE Mono (an already existing SCE used to develop engines with a bore of 260 mm to 400 mm) was the first single cylinder engine installed in Wärtsilä Corporation, it had been noted that improvements could be done in the engine´s control system. Some solutions in the control system could have been designed and implemented better than they actually were. To get a better picture of what to change and how to do it an investigation or an evaluation of the control system on SCE Mono had to be done. There was also a suggestion of using a new kind of PLC, but no one really knew if it would be appropriate for the new system. Therefore different PLC system alternatives had to be investigated. Plans of how to install a similar control system on small SCE were also needed.

1.3 Goals

The main goal of the thesis was to develop a new automation control system for the new small SCE. This plan had to be based on the control system of the existing SCE Mono, with improvements and solutions for the problems found. To achieve a functional plan, different possibilities should be evaluated.

The task also involved defining the number of PLC controllers and the location of them in the new engine control system. When defining the PLCs a few factors needed to be kept in mind, such as the stability of the system, the total costs and the component costs, the overall control system performance, the serviceability, the interface to other external systems, the cable routing and the total cable lengths. To decide which PLC system to use, a comparison between the three different PLC systems currently used by Wärtsilä needed to be done. The comparison should focus on system properties like usability, performance, costs and the impact on the final control system architecture.

As result of the thesis work a layout drawing of the PLC cabinet or cabinets should be made. Some kind of drawing or plan of how the cable routes should be done effectively was needed as well. To achieve a functional layout of the cabinet(s), a certain attention to cable routing and component position need to be considered, since the I/O amount in the new system will be large and troubleshooting and expansion possibilities need to be service friendly and easy. Another important aspect to keep in mind was the future expansion of the control system, as the application is a research engine that often evolves with the research projects performed on it.

2 General information about the Single Cylinder Engine

The single cylinder concept was introduced in Wärtsilä to get a better knowledge of engine behaviours. The main focus with the SCE is to develop and research the combustion system in Wärtsilä engines. As the name tells, the single cylinder engine has only one cylinder, which means that parameters, such as cylinder bore, stroke length and fuel type, can easily be configured. The SCE was designed and built to have a better flexibility and it more easily enables changes needed for different tests than a MCE (Multi Cylinder Engine) does. Since the rebuilding time between different engine setups can be reduced, more tests per year can be performed. With the SCE different fuels can be used, such as CR (Common Rail), DF (Dual Fuel), SG (Spark ignited Gas), conventional diesel and new concepts. Another advantage with a SCE is the enlarged space around the engine, which means that there is more space for instrumentation and other special measurement, where e.g. laser measurements in the combustion chamber have been performed on the SCE. The SCE also allows a more sufficient way of working, when calculations and simulations can be done first and thereafter implemented into the SCE. If successful results are upheld with the SCE, the models can then be implemented to a MCE. [9] [22]

The design of the SCE can be seen in *Figure 2*, where the engine parts and a mass balancing system are shown. Since SCE has only one cylinder, dealing with vibrations is of major importance, and it is not possible to run the engine without special arrangements. To reduce the vibrations the engine is constructed with the mentioned mass balancing system, whose mission is to eliminate the first and second order mass forces. Also a heavy flywheel helps to reduce the vibrations. The mass balancing system is connected to the crankshaft of the engine and uses its own separated lubricating oil system. Furthermore the engine power system consists of a crankshaft, followed by a connecting rod and a piston. There is also a spacer that can be changed according to the stroke wanted. Inside the spacer a cylinder liner is mounted, and when changing cylinder bores both the liner and the piston need to be changed. E.g. in the SCE Mono the cylinder bore can be changed between 260 mm and 400 mm. On top of these parts the cylinder head with valves is mounted (not shown in the figure). [9] [14]

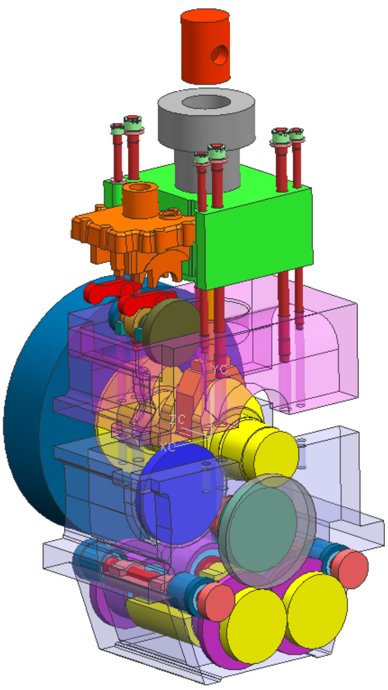

Figure 2. Principal picture of the SCE [9]

2.1 Charge air system

The SCE is built to be a very flexible research engine. Therefore the charge air system has parameters, such as pressure, humidity and temperature, which can easily be controlled. This setup gives Wärtsilä the opportunity to learn how different parameters and setups affect the engine performance. The charge air system is built-up with compressors, valves, tanks (to obtain a stable pressure), air dryers, heaters, coolers and gauges. An overview of the charge air system can be seen in *Figure 3*, where charge air is fed to the two pipes to the left of the picture and fed to the engine, as seen to the right of the picture. [10] [22]

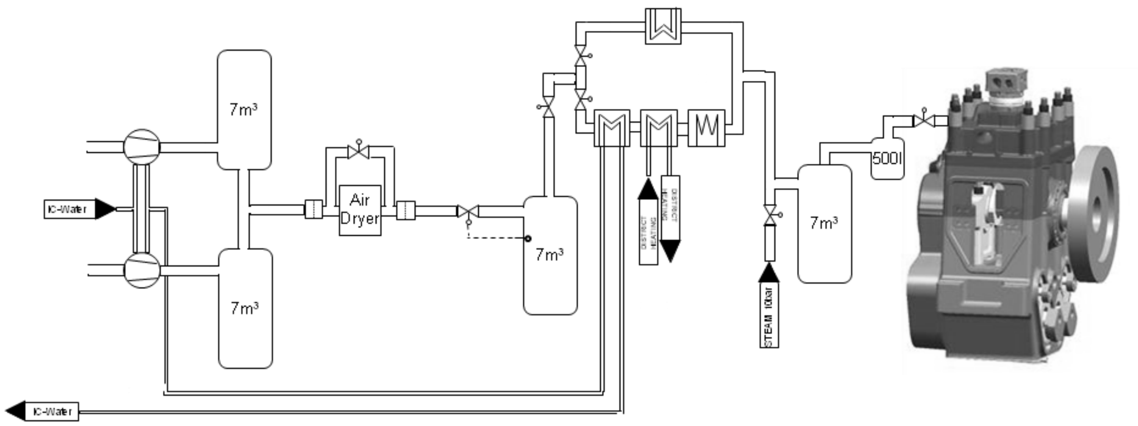

Figure 3. Picture of the charge air system [10]

2.2 Fuel system

At the time of writing the SCE can run on LFO, HFO and LNG fuels. These fuels may be changed for other possible energy solutions in the future. In the engine´s fuel system, flows and the weight of the fuels are carefully monitored, which enables the fuel consumption to be calculated. The fuel consumption is later used for engine optimizations, efficiency calculations and comparisons of the engine efficiency between different engine setups. To be able to use the efficiency calculations and compare them against other Wärtsilä engines, the losses due to friction in the balancing system are also taken into account.

To the SCE a fuel booster unit is connected, which is used for LFO and HFO fuels. The fuel booster controls the flow and measures the consumption of the fuels, and it also heats the HFO to stay viscous. Since there are two different fuel oils connected to the booster unit, there are separate fuel scales, pipes and heaters for LFO and HFO. From the fuel scales the fuel consumption is measured, which is used when counting the engine efficiency. There is also a safety system connected to the engine, which cuts the fuel flow if an emergency situation is detected.

The third choice of fuel is LNG, which is fed to the engine by a gas ramp. The gas ramp controls the pressure of the gas fed to the engine, and it also measures the gas flow, the temperature and the pressure. If gas mode is selected, the gas is fed directly to the air manifold before the inlet valves (while HFO and LFO injection is done directly into the cylinder). The gas is injected into the air manifold, with a 0.5 to 1.5 bars higher pressure than the pressure of the charge air and the gas is thereafter ignited by injecting pilot fuel (diesel) to the gas air mixture. The pilot injection is done directly into the cylinder and an example of the gas injection can be seen in *Figure 4*. [15] [22]

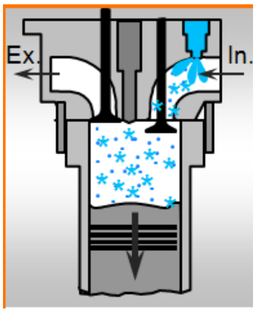

Figure 4. Picture of gas injection and the pilot fuel injection [21]

2.3 Exhaust system

The exhaust system is a bit more complex on the SCE than on a regular Wärtsilä engine, due to the lack of a turbocharger. The backpressure, normally obtained by a turbocharger, is simulated by a buffer tank and two parallel valves of different sizes, which allows a better control accuracy. The backpressure can either be controlled to simulate a certain kind of turbocharger(s) or controlled to maintain a specific set point value. If simulating a certain kind of turbocharger the simulation is done with a lot of different parameters in mind, such as air consumption, exhaust temperature, fuel consumption, air receiver temperature and exhaust cooling water flow and temperature. This simulation is done with a Simulink model in the engine bed automation computer Morphee 2. There is also an EGR (exhaust gas recirculation) system available, which enables some of the exhaust gases to be mixed back to the charge air. This contributes to lower emissions and cleaner exhaust gas. After the backpressure system follows the emission measurement system, where e.g. NOx, CO2, CO, O2 and THC are measured. A picture of this exhaust system can be seen in *Figure 5*, with the main parts of the system shown. [11] [22]

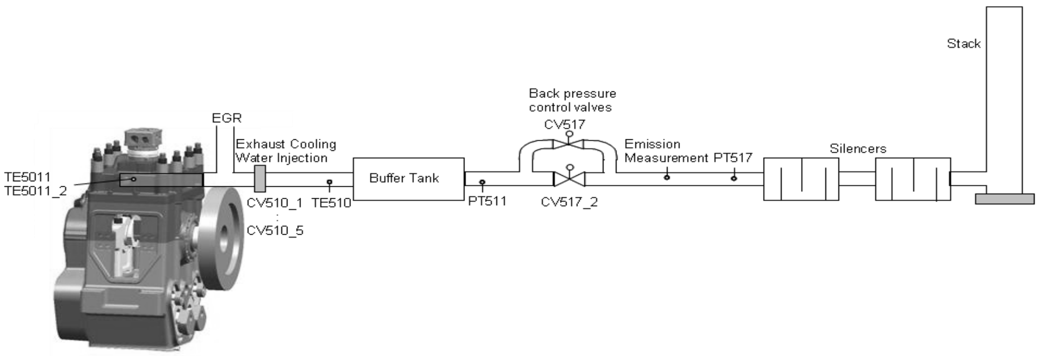

Figure 5. Picture of the exhaust system [11]

2.4 Oil conditioning unit

An oil conditioning unit is also connected to the engine. This oil condition unit is used for the lubrication of the moving parts on the engine. The system can be divided into two parts, where one is used to lubricate the mass balancing system and another is used to lubricate the engine parts. The oil conditioning unit keeps the oil at a predefined temperature and circulates the oil through the different parts. To maintain an efficient pressure the oil pumps are controlled by frequency converters, which keep the pressure between 2 and 5 bars. As a backup, the oil conditioning unit also has a pneumatic backup pump, which will start if power losses or pump failures occur. [22]

2.5 Cooling system

The cooling system is mainly based on seawater cooling, which cools down freshwater through heat exchangers. The freshwater then circulates in the different engine parts that need to be cooled down, e.g. the charge air system, the lubrication oil system, the exhaust gas system, the engine block, the EGR system etc. The engine´s cooling system is a bit different from the other cooling systems, since it is also used to preheat the engine to 90 °C before start up. This system is called HT (high temperature) water system and can be seen in *Figure 6*. [22]

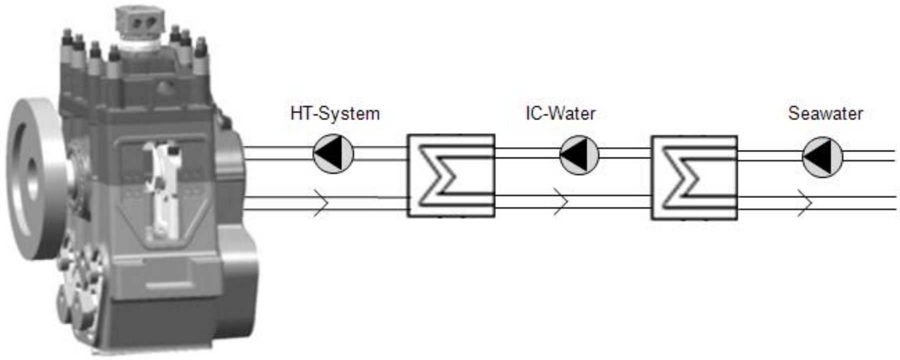

Figure 6. Picture of the cooling system

3 Automation systems on SCE Mono

Since all the auxiliary systems on the SCE are quite special and the SCE is used for testing and research, the automation system on SCE differs a lot from the ones used by Wärtsilä production engines. Compared to a production engine that is delivered to the end customer, there are a lot more different systems combined to one control system on the SCE. On a production engine there is mainly Wärtsilä´s Unic system, which controls the engine, and a PLC system controlling all the peripherals. On the SCE there are instead two PLC systems (one for control and one for measurement), a computer or a test cell automation system (Morphee 2), a fast measuring system (Osiris), Wärtsilä´s Unic system (fuel injection control system) and a DSPACE system (a MicroAutoBox for control of the intake and exhaust valves). These systems, which are combined to one engine control system, are illustrated in *Figure 7*. [16]

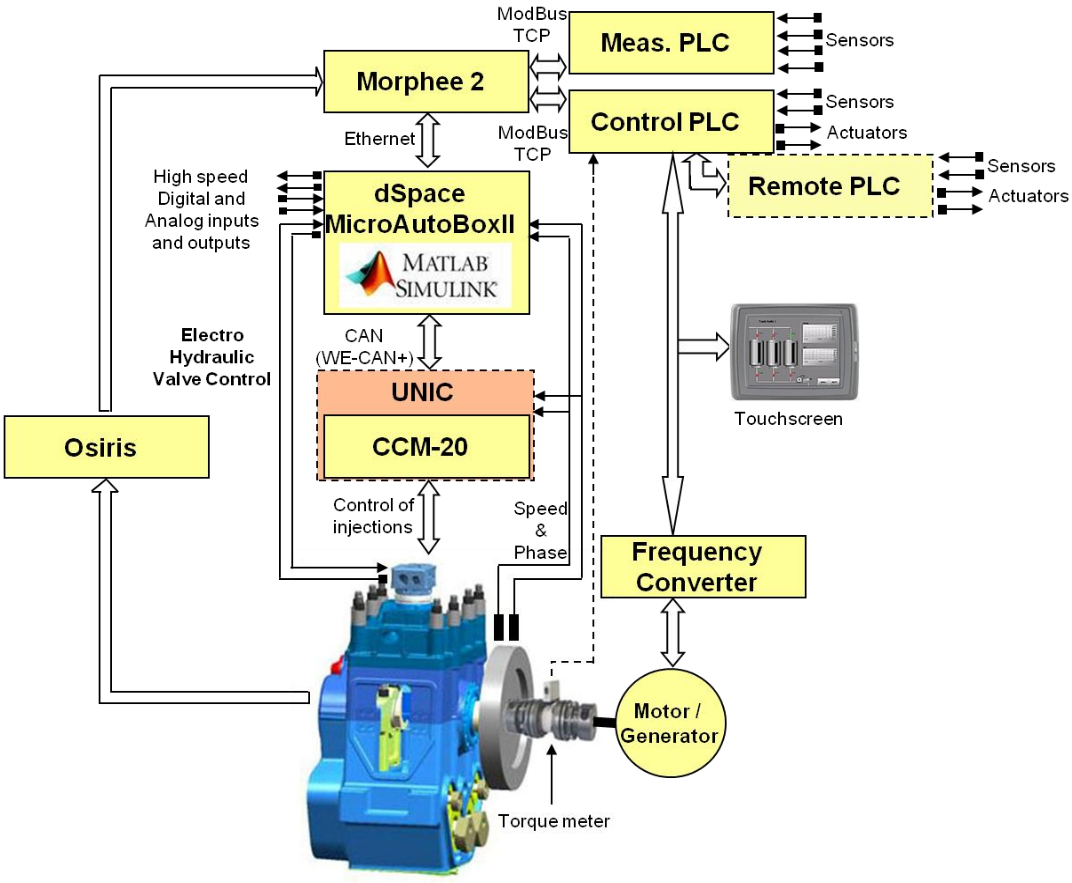

Figure 7. The control system of SCE Mono. [13]

In the engine control system a lot of the control has been chosen to be performed by the PLC system, to which most of the sensors and actuators are connected. Looking at *Figure 7* it can also be noted that the engine is connected to a motor, which works as a motor at engine start-up and a generator when combustion has started. In addition to the PLC system, some of the control is also performed by the Morphee 2 computer, which is a unique real time system for automation, simulation and calibration. The Morphee 2 computer also works as an HMI to the PLC system, with a touch panel connected to the PLC system, working as a backup HMI. [16]

The dSPACE MicroAutoBox and the Wärtsilä Unic system also belong to the engine control system. The task of the MicroAutoBox is to control the exhaust and the intake valves, where the main control of the MicroAutoBox is performed by the Morphee 2 computer. The fuel injection control, on the other hand, is performed by Wärtsilä´s Unic system, where the main control of the Unic system is performed by the Morphee 2 computer. In addition to this system there is also an Osiris system. The Osiris system is used for fast measurements and measures signals that are faster than 10 Hz. [1] [16]

3.1 The PLC system & Morphee 2

While other PLC systems on Wärtsilä engines mainly control the peripheral systems around the engine, on the SCE it also controls a lot of other things, such as the pressure, temperature and moisture of the charge air, the backpressure in the exhaust system, the EGR system, etc. The PLC system that has been used is from Schneider Electric´s Modicon Premium series and the SCE Mono has two different PLC units; one control PLC and one measurement PLC. These PLCs communicate over Modbus TCP/IP with other units and the sample rates used are 1 Hz, and in some cases a faster sample rate of 10 Hz is also used. These sample rates divide the Modbus addresses used into two different areas. In these address areas all signals can be located in the 1 Hz address area, where signals are asked with a 1 Hz interval. In the 10 Hz address area some signals are also located, and these signals are asked with a 10 Hz interval.

There are two different PLC units in the control system. The Main PLC, which is also called the control PLC, is named BAP041 (Bed Automation PLC, test cell 4, PLC cabinet 1). Due to the large amount of I/Os a remote unit called BAP042 is also connected to BAP041. This remote unit uses the CPU of BAP041 and has actually a larger amount of signals connected to it than the main PLC has. The measurement PLC is called BAP044 (BAP043 is reserved for expansion possibilities) and has its own CPU. BAP044 is mainly used for different measurements, while the control is performed by BAP041. These PLCs are connected to a control network, where also the Morphee 2 computer, Osiris and most of the auxiliary equipment are connected. In addition to this, the main PLC (BAP041) is also connected to another backup network with its other network card. The location of these different units in the engine control system can be seen in *Figure 8*. [2] [25]

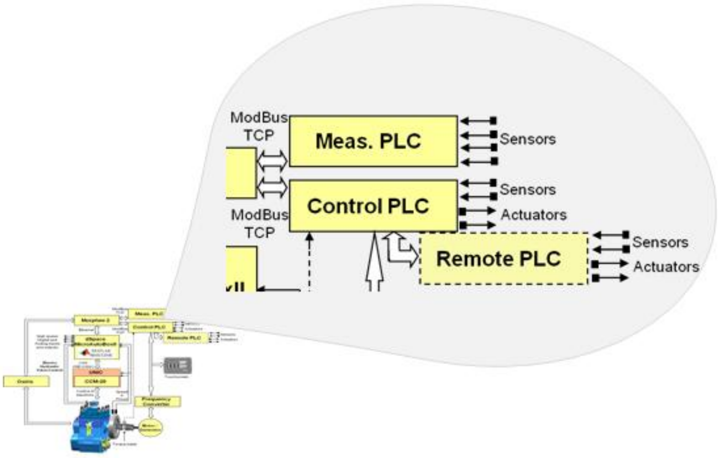

Figure 8. The PLC system in the engine control system.

The PLC system also cooperates with the Morphee 2 computer over Modbus TCP/IP. This test bed automation system is manufactured by D2T PowerTrain and is a computer built for testing purposes. By the manufacturer the Morphee 2 computer is described as:

"A unique system for test bed automation, engine calibration tests implementation & model integration into the test bed (simulation). A real time system working with the real time kernel RTX which warranties a full compatibility with future OS and Hardware" [6]

In the Morphee 2 computer, Simulink models and PIDs can be implemented to control the connected devices. To do this Morphee 2 has several different connection possibilities, e.g. Rs-485, Ethernet and a few I/O pins, and it can communicate with protocols such as CAN, Modbus and Profibus. An example of the platform Morphee 2 uses can be seen in *Figure 9*. The Simulink models implemented into the Morphee 2 platform can be simulated while the engine is running, which allows Wärtsilä to improve their control strategies and develop the engine control system. Morphee 2 also enables offline verifications, can simulate missing items (or extra items such as the mass balancing system) and enable complex calculation functions to be used. [6] [7]

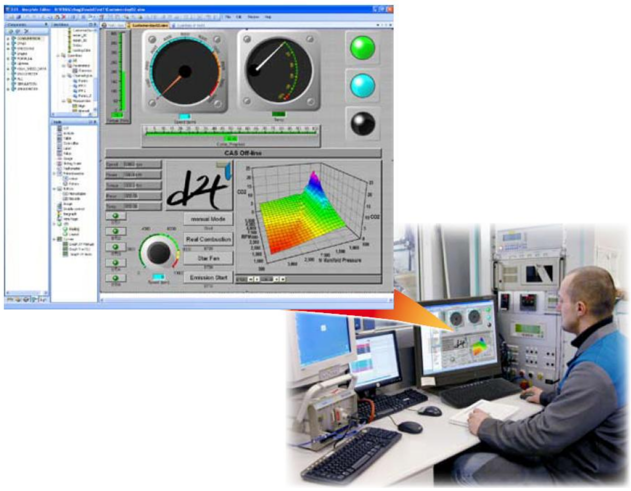

Figure 9. The Morphee 2 platform. [6]

A touch panel from Beijer Electronics is also connected to the PLC system. This touch panel is connected to BAP041 through the measurement network and uses Modbus TCP/IP. The touch panel is planned to be used as a backup unit if the control network gets any fault, which would disable the communication between Morphee 2 and the control PLC (BAP041). The touch panel therefore enables the operator to give commands to the PLC, e.g. to turn off the engine. The touch panel also monitors and displays the values on the engine, such as speed, load and the I/O signals and displays the signals on the screen. [25]

3.2 Engine control system

The fuel injection control in the SCE Mono is performed by Wärtsilä´s Unic system. Except for the fuel injection control, the Unic system also monitors the position of the engine, the knock sensors, the cylinder pressure and the common rail pressure. Although the UNIC system performs the injection, the actual control is done with a real time Simulink model located in the Morphee 2 computer. This Simulink model communicates through Morphee 2 with an LDU-20 (local display unit 20) over TCP/IP. The LDU-20 unit works as a gateway between Ethernet communication and CAN communication, and communicates with a CCM-20 (cylinder control module 20). All necessary actuators and sensors for injection control are connected to the CCM-20. Speed and phase sensors are also connected to the CCM-20 to know when fuel is to be injected.

A MicroAutoBox from dSPACE is also connected to the engine control system. This MicroAutoBox is used to control an EHVA unit, if the engine is setup for electro hydraulic valve control instead of valve control with an ordinary camshaft. DSPACE manufactures and develops different control systems for testing purposes, and describes their MicroAutoBox as a robust and compact stand-alone prototyping unit [8]. This means that outputs and inputs can be configured as preferred, and using a MicroAutoBox enables real time Simulink models to control the outputs. The Simulink models are created and programmed to the MicroAutoBox by the Morphee 2 computer. By using a MicroAutoBox controlling an EHVA unit almost any valve lifting curve can be imitated. To the dSPACE system, the same speed and phase sensors as the Unic system uses are also connected. These sensors are used in the system to know when the lifting of the valves should be performed. [1]

3.3 Fast measurement system

Since the main purpose of the single cylinder engine is to research the combustion cycle, a fast data acquisition system has been installed on the engine. Compared to the other acquisition systems (Morphee 2 and the PLCs), this system enables measurements being taken with a frequency up to 1 MHz and measurements can therefore be taken on engine cycle basis instead of time basis. The system that has been chosen is an Osiris Combustion Analysis System delivered by D2T PowerTrain Engineering, which also delivered the Morphee 2 computer.

The main purpose of the Osiris measurement system is to do a thermo dynamical analysis of the combustion process based on the measured cylinder pressure. This involves calculating the start of the combustion, the heat releases, the burn rates etc. Except for the thermo dynamical analysis, Osiris can also measure other signals acquiring higher sampling rates, such as needle lifts and different pressures, but also critical measurements depending on the engine configuration. Osiris is especially suitable for measurements related to the cyclical combustion process. For angle and revolution measurement a special sensor from AVL is used, which measures the angle on the free wheel end of the crankshaft. Osiris displays critical parameters (e.g. max cylinder pressure or knock) in real time, while other measurements can be calculated and formatted before displayed and stored. The measurements are thereafter saved to a hard drive so that values can be used after a test section has been done. [4] [5]

3.4 The networks of the engine control system

The systems described in the previous chapters mainly communicate with each other through two different Ethernet networks, where the communication protocol mainly used is Modbus. These networks are divided into one control network (192.168.1.xxx) and one measurement or backup network (192.168.2.xxx). An illustration of the networks can be seen in *Figure 10*. Except for the systems described above a few other systems are also connected to these networks. These systems are a PLC programming computer, a MOXA converter and a Mexa system (used for emission measurements), located in the control network. In the measurement network these other systems are fuel scales for the fuel consumption and a Smart

NOx sensor for emission measurements. To illustrate the communication between the devices another illustration was made for each network. These illustrations can be seen in appendices 1 and 2. [25]

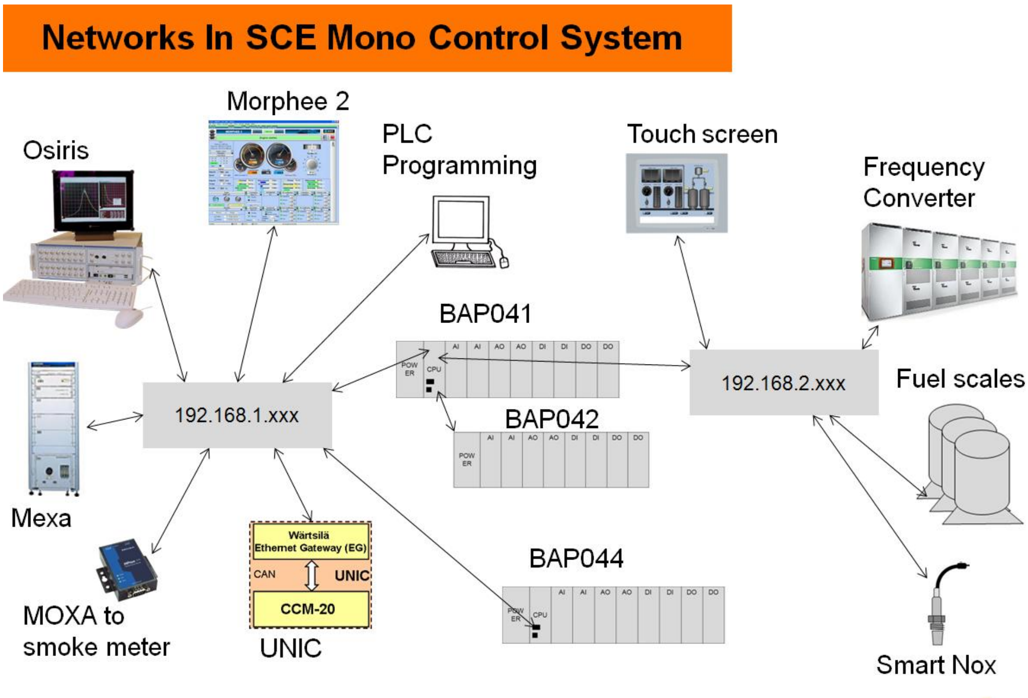

Figure 10. The networks of the SCE Mono control system

3.5 Safety system

To prevent engine damages and emergency situations, the SCE Mono has a safety system installed. This system uses safety relays, sensors, emergency stop buttons and safety switches to trigger certain circuits if an emergency is detected. If an emergency situation is detected by this system, the engine is shut down by the main PLC (BAP041). Also the fuel, the air and the driver voltage to the engine are shut off by the safety system. If the cause that trigged the system hasn't been solved within 30 s, the high voltage main breaker also opens. In addition to this emergency safety system there are safety controls in the other automation systems, which may shut down the engine if necessary. [2] [12]

3.6 Engine control modes

The engine has five different running modes controlled by the PLC, which are emergency stop mode, Rig off mode, Standby mode, Run mode and Combustion mode. Depending on in which mode the engine is, different control loops and PIDs are activated. To change running mode a request of the corresponding mode has to be done. These different running modes are illustrated in *Figure 11*. [16]

When the system is powered up it automatically goes into rig off mode, where all the auxiliary equipment is turned off and only standby mode can be requested. When standby mode is initiated the preheating of the engine is turned on (HT-water, Lubrication oil systems, etc.). From standby mode either rig off mode or run mode can be requested. In run mode the generator works as an electrical motor and ramps up the engine to the requested speed. Run mode also starts some other auxiliary equipment, such as the generator fans, the charge air system, the exhaust system and the fuel boosters. From the run mode, combustion mode or standby mode can be requested. In combustion mode the Unic system starts and fuel injection is thereby activated. This means that combustion starts in the engine and because the frequency converter driving the electrical motor controls the speed, the motor is put back to work as a generator. Combustion mode also activates the dryer and the steam control in the charge air system, exhaust pipe temperature control and EGR control. In addition to these running modes there is also an emergency stop mode, which can be activated from any other mode. This emergency stop mode turns off all auxiliary equipment, but also closes an emergency shut off valve on the engine inlet to quickly shut down the engine. The emergency stop mode is either trigged by the safety system (mentioned in chapter 3.5) or by any of the inbuilt safety controls in the other systems. [16]

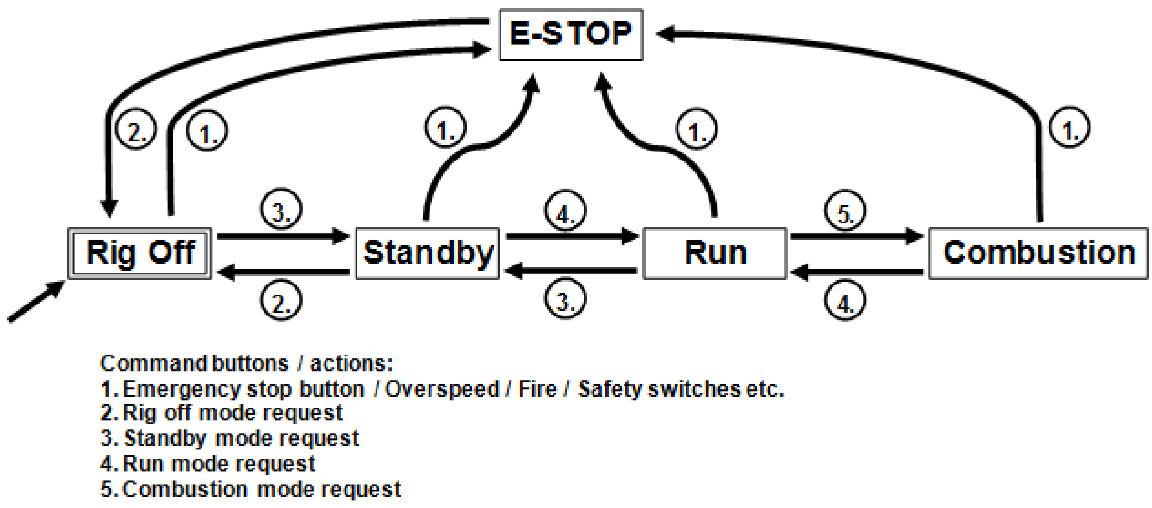

Figure 11. The different running modes on the engine. [16]

In the different run modes the auxiliary systems and the engine are controlled by PIDs and control loops embedded in the PLC. The PIDs in the PLC are built up by function blocks (can be seen in *Figure 12*) called SCE_PI, since they only use the proportional and the integral part of a PID controller. The derivate part is left out from the PLC system, but can be used if an external system is connected to the function block instead. External systems (i.e. Morphee 2) can be connected to the function block, by the use of a tracking function. This means that a tracking value is set to the block, which directly controls the actuator. If this tracking function is preferred, manual mode has to be chosen in the control word of the function block and the input WDog_OK has to be 0. If the demands are not fulfilled, the function block runs in automatic control mode, where the PLC controls the actuator. The WDog_OK signal used is a value that keeps track of the watch dog timer between the external system and the PLC, to ensure that the communication between them works properly. A status word is also used in the function block to describe the operation mode (Auto, Manual, and Error) of the controller. [16]

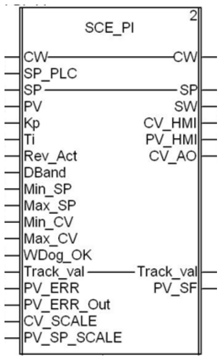

Figure 12. The control block used for PI controllers. [16]

As mentioned earlier there is also a Morphee 2 computer, with its own control interface that can be built as preferred. This control interface can handle several things, such as monitor signals. It can run predefined test sequences, run PIDs to control valves, requested run modes etc. To the Morphee 2 a Simulink model can also be connected, which e.g. communicates with the Unic system. The Simulink model handles the different injections, the knock control, calculate the friction model (also single cylinder to multi cylinder model), BMEP calculations (compensation calculations referred to production engines), turbo charger models, etc. In addition to this the Simulink model also controls the MicroAutoBox. Other simulations and controls may also be implemented in the Simulink model and in Morphee 2, since Morphee 2 is connected to the biggest part of the automation system. [6] [7] [13]

4 Automation system on small Single Cylinder Engine

The automation system on the new single cylinder engine (small SCE) was decided to be quite similar to the engine control system of SCE Mono, since that system fulfilled the requirements that the small SCE demanded. Basing the new engine control system on the one of SCE Mono would reduce the workload, since knowledge of that system already existed and old drawings, programs and models could be reused to fulfil the demands on the new engine. However, it had been noticed that a few things could be improved from the SCE Mono control system and a new cheaper PLC system was proposed to be used.

Therefore several options needed to be evaluated before implementing a similar control system on the new engine. These options will be described and balanced against each other in the following chapters. Another thing that also had to be kept in mind was the charge air system. The charge air system on the small SCE was planned for extension possibilities, since there was a plan that even another SCE will be installed in WVC in the future. This can result in the fact that the charge air system will become common for both the new engines. Thus this aspect also had to be considered in the planning of the new engine control system on the small SCE.

4.1 Pros and cons

After evaluating and documenting the existing control system of the SCE Mono, a few problems were found. These have to be considered before implementing a similar engine control system on the small SCE. The main problem in the SCE Mono test cell is messy or disordered cable entrances in the control cabinets. Cable lengths are generally also very long in the test cell, which has led to high costs since the main cable used is of a special heat and oil resistant type. The use of two different PLCs or CPUs has also been problematic and has contributed to more programming and more traffic on the Modbus network.

Another disadvantage in the control system of SCE Mono is the arrangement of Modbus addresses. It has been pointed out that the driver in the Morphee 2 computer prevents two Modbus addresses placed after each other to be read on the same request made. However, the Modbus addresses of the status word and the control word for an actuator are located after each other, and these values are therefore read by two requests instead of one. Other small problems in the SCE Mono test cell have also been found, such as cable routes blocking cabinet doors, too small connection cabinets, unenclosed PCBs and overheating problems in the cabinet were Morphee, Osiris and the network equipment are placed.

4.2 The new test cell

The new part of the building in WVC, where the small SCE is going to be placed, was under construction when planning the new engine control system. This new part of the laboratory includes a workshop and a test cell for the small SCE but also a test cell for a possible future SCE. The building will be three floors high, with the test cells at the bottom floor. Most of the auxiliary systems will be located inside the test cell, and the draft of the test cell can be seen in *Figure 13.* The parts of the auxiliary system located outside the test cell will be frequency converters, transformers, high voltage switchgears, an exhaust buffer tank (to simulate the backpressure of a turbo charger), compressors and most of the charge air system. These parts will be located in a separated switchgear room and in two different auxiliary rooms (one for the charge air and one for the exhaust system). In the auxiliary system some parts will also be common for all the test cells, which had to be taken into consideration when planning the PLC system. [23]

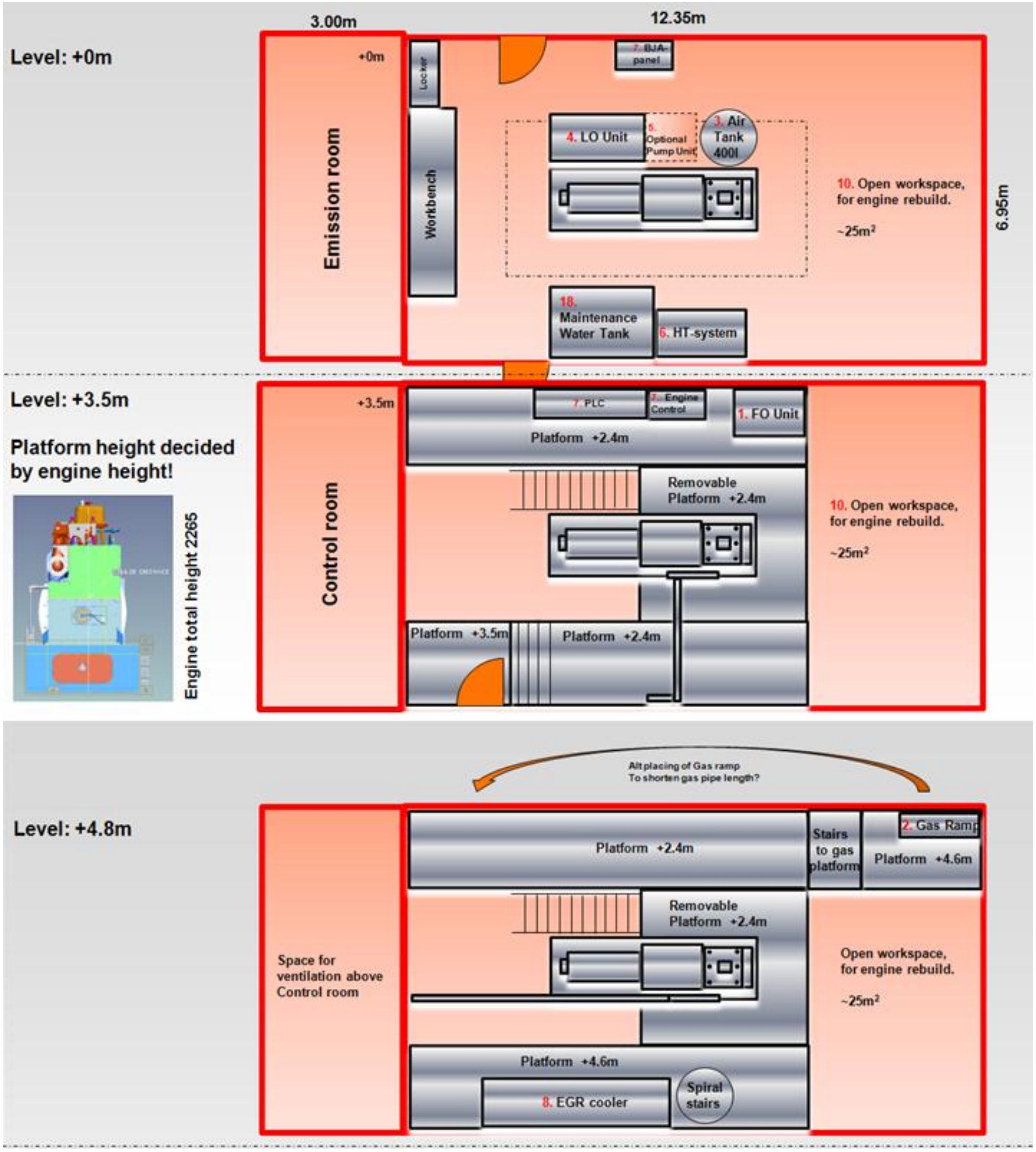

Figure 13. Layout of the test cell to the small SCE. [23]

4.3 Networks and PLC requirements

To be able to decide which PLC family to use in the new engine control system, the amount of PLCs or PLC CPUs and the amount of Modbus networks were first decided on. These decisions were based on the SCE Mono control system, where two different PLCs (measurement and control) with one remote PLC unit and two different Modbus networks (one for control and one for backup) were used.

From experiences with SCE Mono it had been pointed out that using two different PLCs will result in more programming and more traffic on the Modbus network. The advantages of this concept were that the measurement and the control signals were divided from each other and the use of two different PLC CPUs may also be better in safety perspectives. E.g. the engine could still run if the measurement PLC crashes. However, running the SCE without the measurement PLC is of no use, since the SCE is a research engine and is run to get measurements. It was therefore decided to use one PLC CPU instead of two in the engine control system of the small SCE, as long as one CPU could handle the entire I/O amount located in the engine test cell.

To get better connectivity and to connect all the signals scattered around the test cell, a remote (BAP042) unit had been connected to the SCE Monos control PLC (BAP041). This remote unit uses a special communication cable, provided by the PLC manufacturer, to communicate with the main unit or the CPU of the PLC. This means that the I/O boards in the remote unit can be controlled in the same way as if they had been located in the same back panel as the CPU. Since the remote unit has worked fine in the control system of SCE Mono, remote units will also be used in the new installation, if the I/O amount requires it.

The Modbus networks had been divided into two different networks in the SCE Mono control system. This had been done for safety aspects. If one network stops working, the control PLC can still be controlled and monitored, either by the touch panel or by the Morphee 2 computer, since these units are located on different networks. The question was if the same concept, with two networks, should be used in the control system of the small SCE or if one Modbus network would be enough. The topic was therefore examined. The advantages of using one network instead of two would be few (mostly cost prospective), and using one network would exclude the safety advantages of two networks. Even if one network could easily handle the data traffic, it was decided to also use two networks in the new control system.

4.4 The PLC system

Wärtsilä aims to get cost-effective and robust control PLCs for their engines and control systems, and also consumes a large amount of PLCs per year. The market is therefore examined for cost-effective solutions, which will fulfil certain pre-defined requirements. Wärtsilä has got the most competitive offer from Schneider Electrics with their Modicon PLCs and that is why Modicon is the PLC brand used at the moment. The PLC families used are Quantum, Premium and M340, where Quantum and Premium have been used for a longer time and M340 is a newer PLC family. M340 is mostly used by the division Power Plant. It is also the cheapest one among these three candidates. Modicon describes these families as Quantum and Premium belonging to the high end controller group, while M340 belongs to the mid range controllers. The exact description that the Modicon uses is:

"Modicon® Quantum™ PLC

The Modicon Quantum PLC is the powerhouse of the Modicon family. It's scalable, modular architecture is configurable to meet the needs of even the most critical solutions, from a single rack system to a plantwide architecture. It is ideally suited to industries that require continuous operation, rapid responsiveness and high availability through redundant backup, and achieves optimum cycle times, while integrating increased communication connectivity, diagnostics, memory flexibility and data storage

Modicon® Premium™ PLC

Delivering more flexibility and openness, the Modicon Premium PLC offers a highly versatile, cost-effective control solution. It enables you to standardize on a single platform for multiple discrete manufacturing and process control applications while at the same time, allowing you to take advantage of a flexible architecture that integrates multiple CPU levels, plug-and-play rack support and open communication standards. It also features multi-axis interpolated motion control, weigh scale monitoring, integrated Preventa™safety relays and reflex functionality for fast, independent processing of critical I/O.

Modicon® M340™ PAC

Extremely powerful, rugged and compact, the Modicon M340 Programmable Automation Controller (PAC) provides cutting-edge features and high-end performance in a mid-range processor. Using commercial integrated circuit technology, the M340 utilizes modern data networking to interact with distributed I/O, drives, other PLC devices, and enterprise-type entities. It also uses the same Unity™ application development software as the Quantum, Premium and Atrium equipment, making it easy to quickly select, program and implement the controller to optimally manage simple to complex applications. [17]

4.4.1 Comparison of the PLC families

For the small SCE it was decided to select a PLC system among the three PLC families that Wärtsilä was using, based on a number of prerequisites. One proposal was to use M340, since that was the cheapest one, but no one really knew if it would be appropriate and meet the requirements that the small SCE demanded. Premium could also be considered as a choice, as the control system on SCE Mono was based on Premium. Considering the costs, Quantum was more favourable than Premium and has been used more widely in the engine laboratory. Despite the price benefit, there was no guarantee that Quantum would be cheaper, since the same parts aren't used in both of the PLC systems. The questions, possibilities and differences needed to be investigated and a comparison was made to be able to decide which PLC family to use.

The comparison was based on the CPU with the best features in the different families, with and without expansion modules. The biggest differences noted can be seen in appendix 3. After the comparison had been made, no PLC family could yet be excluded, due to the fact that they all showed good results and the I/O amount in the new control system wasn't yet known. Therefore, the I/O amount in the PLC system needed to be estimated and since the PI schematic wasn't yet finalized, calculations were made based on the SCE Mono´s control system, experiences and best available information at the point of the decision. The I/O amount was mainly calculated by means of the drawings and schematics on SCE Mono, where signals known not to be used in the new system were removed. With all three PLC cabinets in mind, the total I/O amount counted can be seen in *Figure 14*. Since it was decided to only use one PLC in this new control system, the PLC to be chosen needed to be able to handle the entire I/O amount estimated.

Existing I/Os

	BAP041	BAP042	BAP044	I/O Amount Total
AI	80	96	80	**256**
AO	20	32	4	**56**
DI	32	64	32	**128**
DO	32	64	32	**128**
TOTAL	111	216	47	**374**

I/Os used

	BAP041	BAP042	BAP044	I/O Amount Total
AI	73	89	32	**194**
AO	12	24	0	**36**
DI	12	43	8	**63**
DO	14	60	7	**81**
TOTAL	111	216	47	**374**

Figure 14. The I/O amount in the PLC system of SCE Mono.

4.4.2 Result of the comparison

The comparison showed that all the PLC families could be used, but if M340 is used, expansion possibilities will be very limited. Due to the fact that the total analogue I/O capacity on M340 is 256 channels, and the estimated amount of analogue I/Os in the new test cell almost exceeds this number, 230 analogue I/Os were estimated to be used. Another big disadvantage with M340 was the distance allowed for connecting remote units, which was only 30 m. This would e.g. not allow a main PLC unit to be used in the compressor room with a remote unit placed near the engine, as within the control system of SCE Mono. Therefore M340 wasn't an option anymore and the choice was left between Premium and Quantum.

Both Premium and Quantum could be used and the prices of these two families were therefore compared. The CPUs chosen when comparing the prices were TSXP576634M from the Premium series and 140CPU67160 from the Quantum series. Backplanes, communication cards, cables, connection modules, power modules and I/O cards were included in this comparison. In the end it could be noted that using Premium PLC would be 7366 € more expensive than using Quantum. Even if pricing was in favour of the Quantum system, the Premium system offered quite many advantages for practical reasons. The Premium system would have better serviceability since spare parts already existed, and programming advantages as the program from SCE Mono could be reused and thereby the workload would be decreased. Other synergies could also be noted and the choice was therefore Modicon Premium.

4.4.3 Modules of the PLC

The PLC family Modicon Premium is built with a back panel and different kinds of modules and an example of this type of construction can be seen in *Figure 15*. Choosing the different kinds of modules and also the sizes of the back panel, was quite straight forward, since they had to be the same kind of parts as in the SCE Mono PLC system, otherwise the synergetic effects would be lost.

Using exactly the same PLC part setup as in the SCE Mono PLC system had one disadvantage, which was the power supplies of the back panels. These power supplies run on 230 VAC, but the UPS power system in the test cell is built to run on 110 VDC. This has resulted in having an inverter to convert the 110 VDC to 230 VAC for the PLC system. To investigate if there really wasn't any other kind of power supply that could be used, a calculation was made according to the manufacturer´s example. This calculation can be seen in appendix 4 and shows that the choice of power supply had been right in the SCE Mono installation when the TSX PSY 8500 was used. This means that an inverter needs to be used in the new test cell as well, since the UPS system in the new test cell will also run on 110 VDC (an alternative inverter could also be one converting from 110 VDC to 110 VAC).

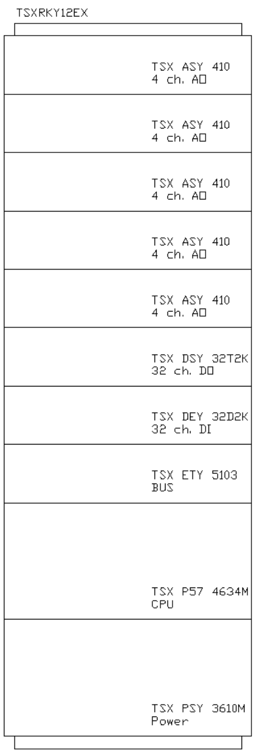

Figure 15. The main back panel with a power unit, the CPU, a network card and 7 I/O modules.

4.5 The new PLC structure

To proceed with the planning, the amount of remote units needed to be decided on. Moreover, a way of getting a better order in the cabinets needed to be figured out. In the control system of SCE Mono, the remote unit (BAP042) and the measure PLC (BAP044) were placed near the engine, while the main control PLC (BAP041) was placed in the compressor room separated from the test cell. Since most of the I/O amount is on and close to the engine, BAP042 and BAP044 were overcrowded with cables and components while BAP041 was the only PLC cabinet properly sized for the I/O amount connected. An example of the overcrowding can be seen in *Figure 16*, where the main reason for the overcrowding was that the control system had expanded gradually, which the original layout wasn't built for.

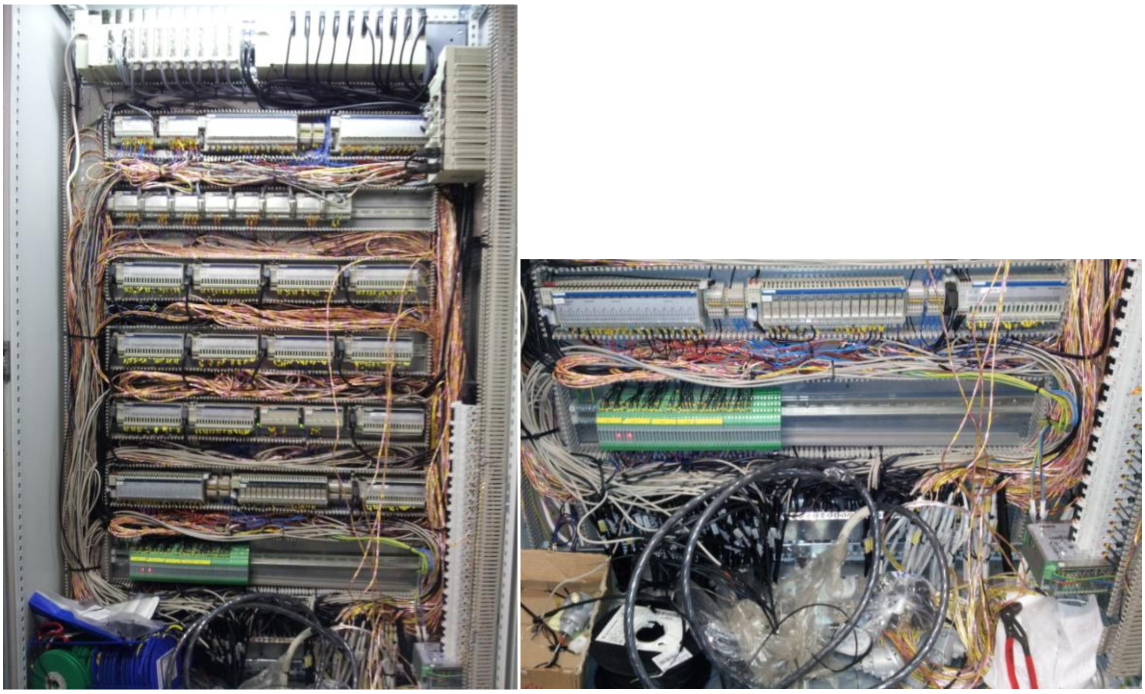

Figure 16. PLC control cabinet in the SCE Mono engine control system.

In *Figure 16* it can be noticed that the covers on the cable routes couldn't be fitted in the cabinet anymore, and cables had been placed on top of each other. This makes it difficult to remove old cables, add new ones and to locate one particular cable in the mess. The side of the cabinet has also been used for fuses and cable routes, which has proven to contribute to the disturbance.

4.5.1 Signal amount and remote units

Contrary to the control system of SCE Mono it was decided that the placement of the main PLC should be close to the engine, since the largest I/O amount had been located there. This placement will facilitate the rebuilding and expanding possibilities of the control system and keep the total cable costs down. To be able to determine the size of the main PLC cabinet, the prior estimation of I/O amount was analysed once more, when new knowledge of the upcoming control system had been known. As a result it could be noted that the definitive smallest amount of I/Os were 63 DI, 81 DO, 36 AO and 194 AI. In addition to these I/Os the expansion possibilities needed to be taken into account and signals could also be added to the system before finalization. Some of the I/O amount could also be placed in remote units, which would reduce the amount of cables to the main PLC cabinet. One remote unit could be located in the charge air room, where the main unit had been located in the SCE Mono control system. Placing a remote unit in the charge air room would even be profitable, since cables can be saved. The calculated gain in cable costs with the use of a remote unit is approximately 2600 € and an extra full sized cabinet will cost about 1500 €.

$$50 \cdot 25\, m \cdot 2.34\, \frac{€}{m} - 281.40\, € \approx 2600\, €$$

(50 cables, 25 m distance, 2.34 €/m tefzel costs and 281.40 € in connection cable to the remote unit)

Another big benefit by using a remote unit in the charge air room is the future aspects of another upcoming big SCE. If a big SCE is installed in the future, the charge air system will be designed to be rebuildable and become a common system for the two new single cylinder engines. In that case the remote unit will be equipped with its own CPU and become a separated common PLC system, which will handle the charge air system for the two different engines. Therefore the first two card spaces will be left unconnected for a possible CPU.

4.5.2 Reduction of cable consumption

A possible solution for the overcrowding in the test cell and the large cable consumption could be to use bigger cable cabinets, where all the PLC parts could be better scattered. This would allow the cable entrances to be scattered over a larger area and thereby create a better order. However this wouldn't reduce the total cable amount in the test cell, and a large cabinet requires more space. Another alternative could be to use several remote units strategically situated around the engine test cell, which would divide the signals in different cabinets and enable shorter cable distances. On the other hand this solution would require even more space than using one big cabinet. The total price would increase because of the increased number of cabinets and, if using a remote unit a large amount of the signals needs to be connected to it to make a remote unit profitable. The third alternative would be to combine the signals into connection boxes (CBs) before connecting the signals to the main PLC cabinet. This would reduce the amount of cables in the PLC cabinet but also reduce the total consumption of cables in the test cell. The disadvantage of this solution would be that more connection points are used, which would lead to another possible fault source in the control system.

4.5.3 Overcrowding in the cabinets

From experiences with the SCE Mono PLC system it could be noted that to use only two PLC cabinets in the test cell wasn't effective enough, since they had become overcrowded. To fit any more cabinets into the test cell would also be hard, but could be done if really necessary.

If remote units are used, it would be good if an entire back panel could be used and not just some channels in an I/O card. As an example there were around 80 available channels in one back panel in the SCE Mono control system. Since remote units also occupy much more space than a CB, remote units can't be used to the same extent as CBs. Connection boxes on the other hand had only been used in ATEX areas and in some other special cases in the SCE Mono control system. These CBs could therefore be used in a wider area in the new test cell, which would help reducing the total cable consumption. In a cost related way CBs will quickly be saved in avoided cable costs.

To estimate when a CB becomes profitable a quick calculation was done, where the prices used were; 300 € for a CB, 2.34 €/m for tefzel 2x0.75, 5.92 €/m for jamak 24x2x0.5 and 3.15 €/m for jamak 12x2x0.5. The estimated distances can be seen below:

With 12 – pair trunk cable: $m = \frac{300\ €}{11 \cdot 2.34 \frac{€}{\mathrm{m}} - 3.15 \frac{€}{\mathrm{m}}} = 13.3\ \mathrm{m}$

(last pair used for power)

With 24 – pair trunk cable: $m = \frac{300\ €}{23 \cdot 2.34 \frac{€}{\mathrm{m}} - 5.92 \frac{€}{\mathrm{m}}} = 6.3\ \mathrm{m}$

(last pair used for power)

The calculations show that the distances do not need to be that long before a CB becomes profitable to use, and that a CB can be placed where the I/O amount isn't big enough for a remote unit to be located. As converters will also be used in the control system, they could be placed in connection boxes instead of in the main cabinet. This would eliminate the extra connection points, which would otherwise occur when row clamps are used. This would also contribute to reducing possible fault sources. Placing the converters close to the sensors gives a 4-20 mA signal in a longer part of the transmission, which is better regarding disturbances. The placement of the converters would also contribute to making CBs become more profitable, since space will be saved in the main PLC cabinet.

4.5.4 Signals to locate in connection boxes

To figure out which signals to place in the CBs and whether it would be enough to place only the converters in CBs, the signals of the upcoming control system needed to be counted even more carefully. This was done by comparing the PI schematics that existed for the small SCE, a reduced I/O list devised from the I/O list of SCE Mono, and the PI schematics of the SCE Mono. As a result 291 signals were estimated to be used in the new main PLC cabinet. By counting the signals using PT-100 and thermocouples as sensors, 98 converters were estimated to be necessary. Of these 98 converters 68 would be located in the test cell and the other 30 in the charge air room. This means that 68 cables could be saved in the main PLC cabinet and 223 signals would be left in the main PLC cabinet. To reduce this number even more, all the signals using pressure sensors could also be placed in the CBs. Placing the PT signals in CBs would have a disadvantage, because row clamps need to be used. However, the advantages would be even bigger, since another 49 cables (if the extra trunk cables aren't counted) could be saved in the main cabinet and a total of 117 signals could be connected through connection boxes, instead of directly to the main PLC cabinet.

To get a better picture of where these signals were going to be located and where to place the CBs, a draft was made that can be seen in *Figure 17*. In this draft the placement of the CBs is also enclosed. As there are many signals at the same spots, the thought when positioning the CBs was to use a trunk cable with 24 pairs, which would enable up to 23 signals connected to one CB. As can be seen in the draft, almost all of the CBs will also have some extra pairs unused, which enables expansion possibilities.

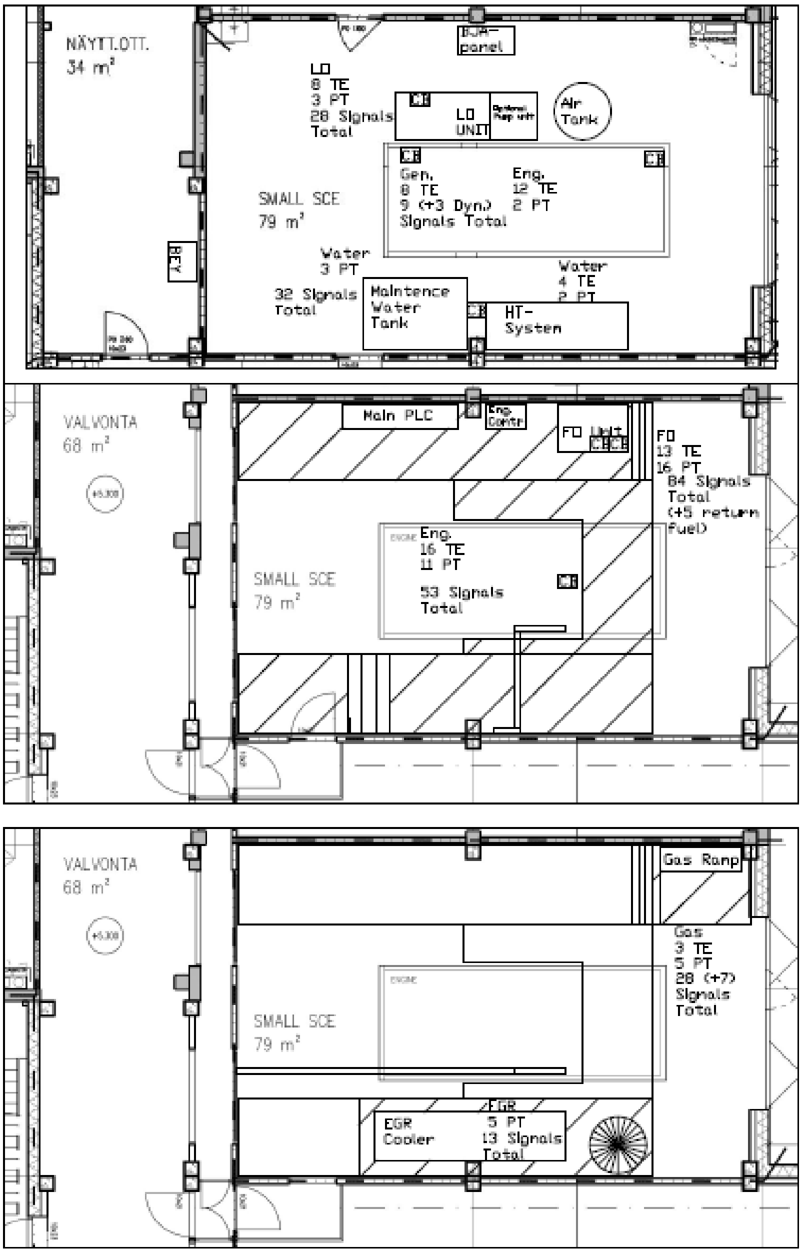

Figure 17. Draft over where the signals are going to be located

In *Figure 17* it can also be noted that the main PLC cabinet is deployed. The main cabinet was placed in the middle platform, because this would shorten the cable distances. As the south part of the test cell was already occupied, the main PLC cabinet will be located in the north part of the test cell. The size of the main cabinet wasn't yet decided on, which had to be done in order to determine if it will fit at this location.

4.5.5 The size and amount of the PLC cabinets

If no remote units (except the one in the charge air room) are going to be used in the test cell and the temperature and pressure sensors are connected through CBs, about 200 cables will be connected to the main PLC cabinet. This would correspond to the cable amount connected to the remote unit (BAP042) in the SCE Mono control system (*Figure 16*). As previously noted this cable amount was too large compared to the size of the cable cabinet. This means that if the entire cable amount is connected to one cabinet in the new test cell, the main cabinet will have to be wider than 1.2 m (width of BAP042). To estimate the width of the new main cabinet, the cable amount was compared to the width of the main cabinet (BAP041) in the SCE Mono installation, since this cabinet was the only cabinet properly sized for the cable amount connected there. This cabinet also had a width of 1.2 m, but the cable amount in it was 113 cables, which means that the width of the new main cabinet should be:

$$\frac{1.2\ m}{113} \cdot 200 \approx 2.1\ m$$

Exploring the market for cabinets shows that the widest cabinet available has a width of 1.6 m. However, using several small cabinets and join them together into one large cabinet is also possible. E.g. three 0.8 m wide cabinets could be assembled together into one cabinet with a width of 2.4 m, which would serve our case and also leave some space for expansion possibilities.

Another option would be to divide these three cabinets into the different floors of the platform and use one of them as main cabinet and the others as remote units. However, placing a remote unit at the bottom floor isn’t a good option if cable routes are taken into account. The cable routes will be located in the ceiling of each floor and the cable entrances of the cabinet are located at the bottom of it, which means that the cable distances are shorter if signals are connected to a cabinet on top of the corresponding floor. The alternative would therefore be to use one main cabinet and one remote unit. To get the signals best divided into these two cabinets, one should be located in the northern part of the test cell and the other in the southern part of the test cell. This option would contribute to reducing the cable consumption and divide the signals in the test cell into two parts. However, the total order in the test cell would be affected, as there would be different cable markings for the two cabinets, more drawings, fuses in two different cabinets, etc. To determine which signals to connect to which cabinet would be hard. The use of a remote unit in the test cell would also question the point of using CBs, since the main ideas of both CBs and remote units are similar. The southern part of the test cell was also planned to be occupied by auxiliary systems, which means that a remote unit would be hard to fit in there. Therefore it was decided to join all the three cabinets into one.

4.5.6 Summary of the PLC structure

As a result the plan was to place the main cabinet on the second floor of the test platform, to scatter CBs around the test cell and to use one remote unit in the charge air room. The control system can then be expanded by using CBs, since it is easy to connect another CB to the control system. This is done by using a singular trunk cable. The total amount of CBs when designing the control system would be seven CBs in the test cell, but also two CBs in the charge air room since eight pressure signals and 30 temperature signals will be located there. It was also decided that the CBs should use the cable type jamak 24x2x0.5 as trunk cable, where the last pair works as current feed to the CBs.

4.6 Cable routes

A plan of where the cable routes should be located could now be made, after the placement of the auxiliary systems, the cabinets and the connection boxes were settled. When deciding where to place the cable routes, all of the different engine control cabinets had to be considered, i.e. the PLC cabinets, CBs, the engine control cabinet, the BEY cabinet (where Morphee 2, Osiris and network equipment will be located) and the BJA panel (cabinet for LV equipments). The cable ladders will either have a width of 30 cm or a width of 50 cm, depending on the signal amount. To know where to place them a draft was made. The draft illustrates where the cable routes should be located and can be seen in *Figure 18.* As can be seen the ladders between the floors are left out. These ladders will be located in the corner of the test cell and on each side of the main PLC cabinet, and will have a width of 50 cm. In addition to these, smaller 30 cm ladders can be located between the floors, where the auxiliary equipment requires it.

Another idea regarding the cable routes was to equip the cabinets with base plinths. This would result in a good order in the cable routes near the cabinets, since cables coming from above could be connected through the base plinths and to the bottom of the cabinet. Cables could then also be connected at the same floor as the cabinet, instead of having cable routes going from one floor to the floor beneath. This will also lead to shorter cable distances.

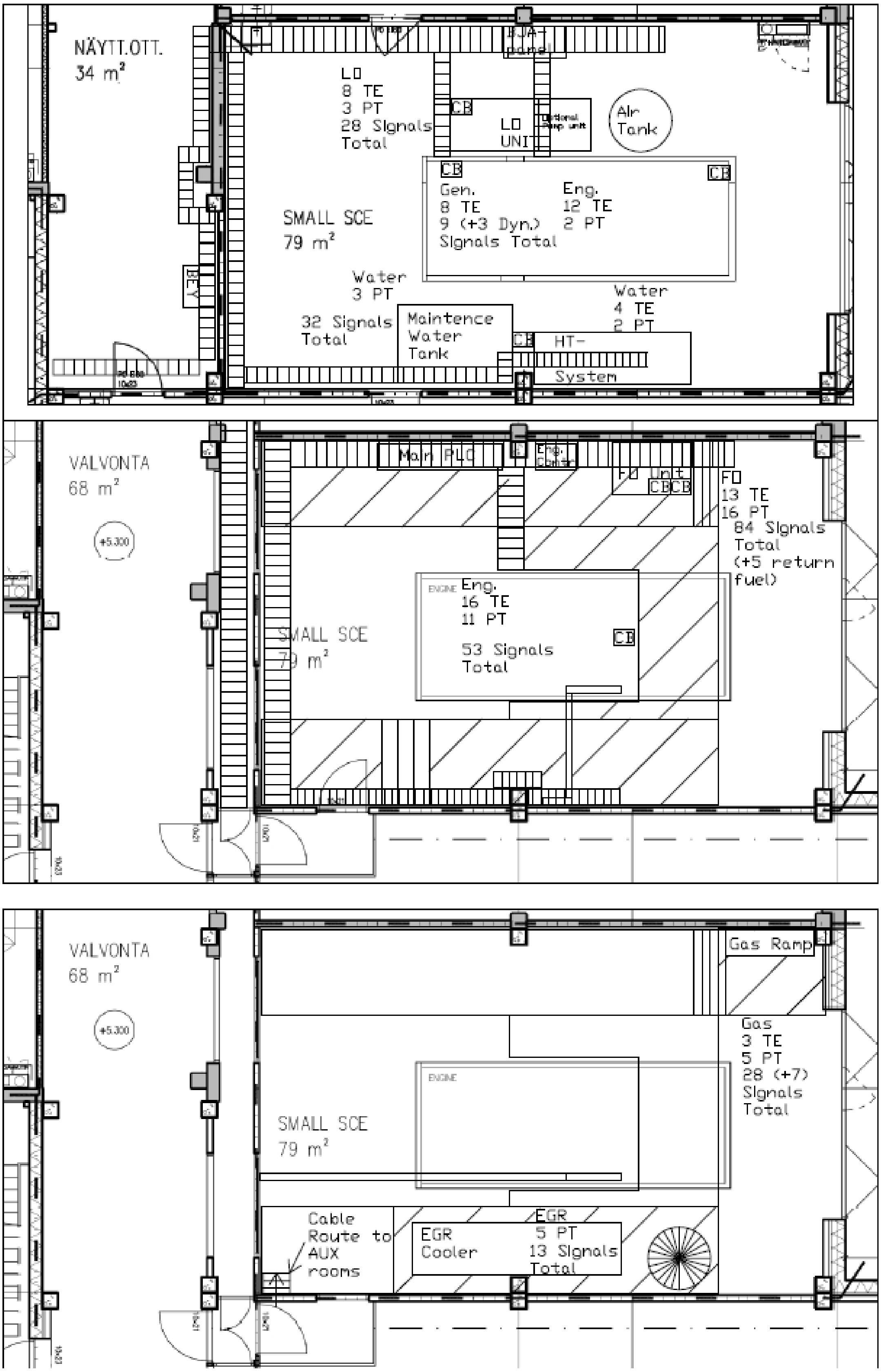

Figure 18. Draft of the positioning of cable routes.

4.7 Cabinet layout

When all essential parts of the control system were determined, the designing of the cabinets could begin. The different PLC cabinets were to be as follows: one main PLC cabinet in the test cell, one remote unit in the charge air room (AUX room 2), and nine CBs scattered around in the engine control system. These will all have a name beginning with BAP (Bed Automation PLC), as in the SCE Mono control system, and because the test cell was decided to be named test cell 7, the name of the cabinets became to be BAP071 for the main PLC cabinet and BAP072 for the remote unit. The connection boxes will be named after the PLC cabinet they are connected to, with a continuous running number depending on the number of CB, e.g. BAP071_CB1.

4.7.1 The main PLC cabinet BAP071

The width of the main cabinet was going to be 2.4 m and to save space on the platform, the depth was decided to be 0.5 m (instead of 0.6 m normally used in the engine laboratory). The height of the cabinet could be chosen as preferred and was therefore decided to be 2 m. The cabinet also needs to have a good IP class to protect the PLC parts from dirt and dust. To get a good IP class, the cable entrances will also be located in the bottom of the cabinet. This means that a socket needs to be used to enable cable entrances at the same floor as the cabinet. A socket with a height of 20 cm was therefore chosen, which enables cable ladders to be connected to each side of the cabinet. This means that the cable routes to and from the main cabinet would be divided into three different routes, one from each side of the cabinet and one from the bottom of the cabinet through the platform. After all the major decisions were made, a layout picture of the main PLC cabinet could be drawn, which can be seen in *Figure 19*.

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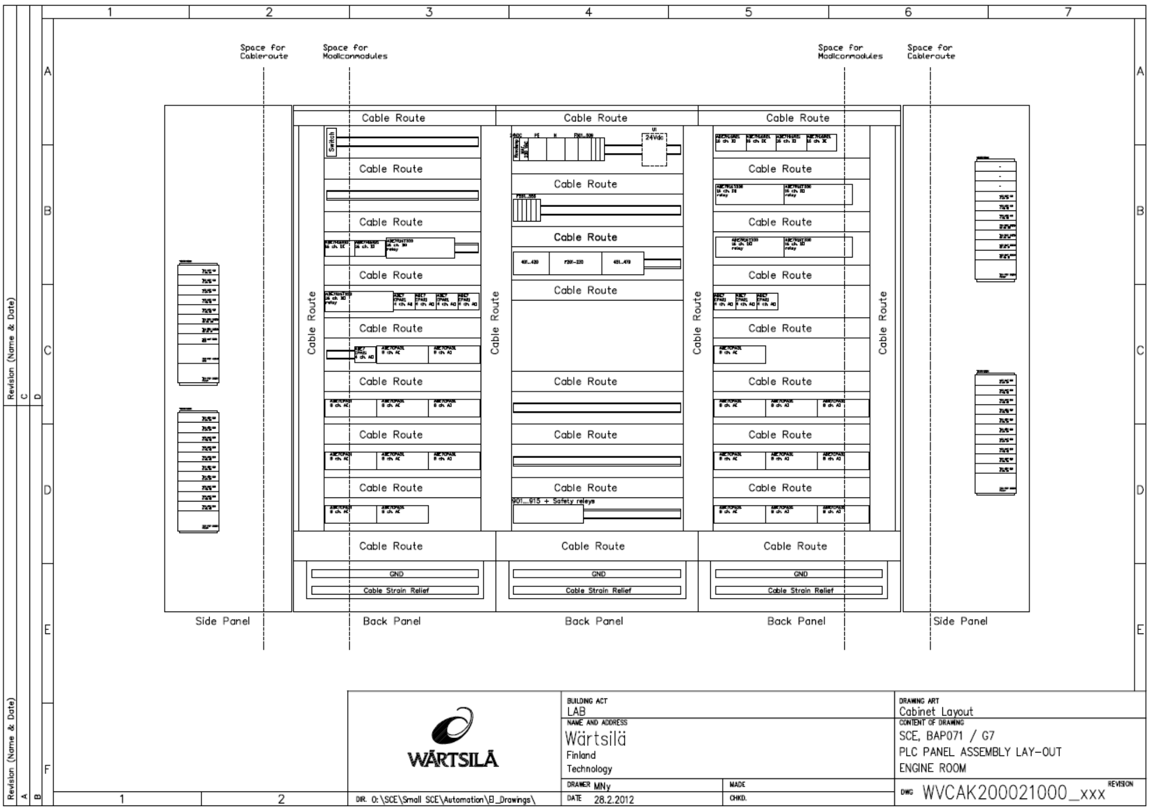

Figure 19. The layout picture of the main PLC cabinet BAP071.

As can be seen in the layout drawing (*Figure 19*), the three 80 cm wide cabinets are drawn as one full 2.4 m wide cabinet. The idea is therefore to join all cabinets together into one large cabinet, and by using cable trunks cover the gaps between the back panels. In the drawing the PLC back panels have been placed at the sides of the cabinet, which will free space on the back panel of the cabinet and leave more space for other equipment. Since telefast units will also be used (these are different kinds of connection terminals for the I/O boards), the PLC back panels can easily be located at the sides of the cabinet. This means that all connections to and from the PLC are done into the telefast units and when new signals are connected to the PLC system, no connections to the back panels have to be done. The telefast units are located at the back panel of the cabinets, which allows an easy access to them and facilitates connections of new signals to the PLC system. In addition to the PLC parts, some fuses, terminals, power supplies and switches will also be located in this cabinet. These parts are planned to be located in the middle part of the cabinet, where some space has been left for expansion possibilities. In the bottom of the cabinet, cable clamp rails are placed and also earth bars for the grounding of equipment and cable shields.

4.7.2 The cabinet of the remote unit BAP072

A layout picture of the cabinet to the remote unit was also made. This layout can be seen below in *Figure 20*. The layout is quite similar to the layout of the main PLC cabinet. The size of this cabinet is 800x2000x500 mm (width, height, and depth) and this cabinet will also use a base plinth of 20 cm height.

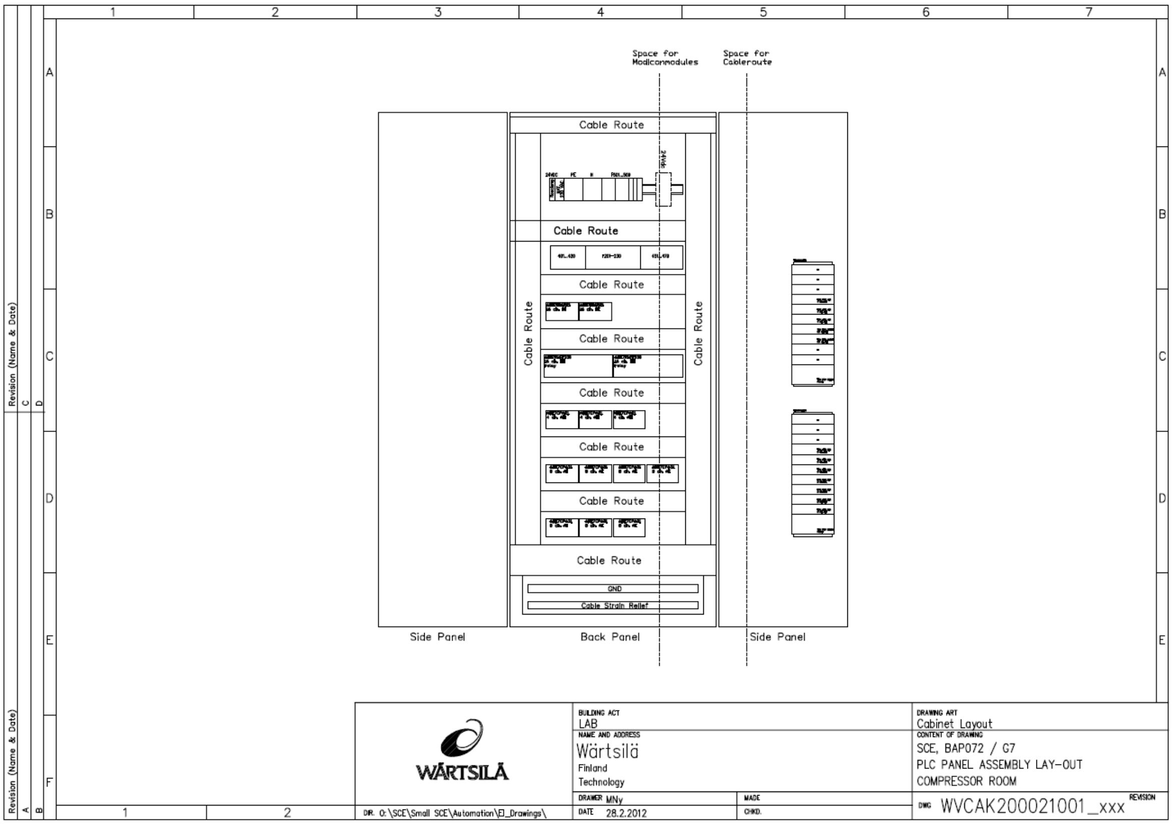

Figure 20. The layout picture of the remote unit cabinet BAP072.

Two PLC back panels are drawn in the cabinet, even though just one will be located there. The other one is drawn for the possibility of making this remote PLC to a common charge air PLC, in case another single cylinder engine will be installed in the future. This means that another back panel is also required to handle the amount of I/Os. In the upper part of the cabinet a power source, terminal plinths, fuses and a switch are planned to be located and below these the telefast units will be located. In other respects the cabinet is similar to the main PLC cabinet.

4.7.3 The connection boxes

The connection boxes were planned to have a size of 300x400x120 mm (width, height, and depth). This is deep enough for fitting the signal converters needed for PT-100 and thermocouples, and big enough for fitting up to 30 converters into one box. This means that a trunk cable with 24 pairs can be used and 23 signals can be merged into one cable. A layout picture was also drawn of a CB, which can be seen in *Figure 21*.

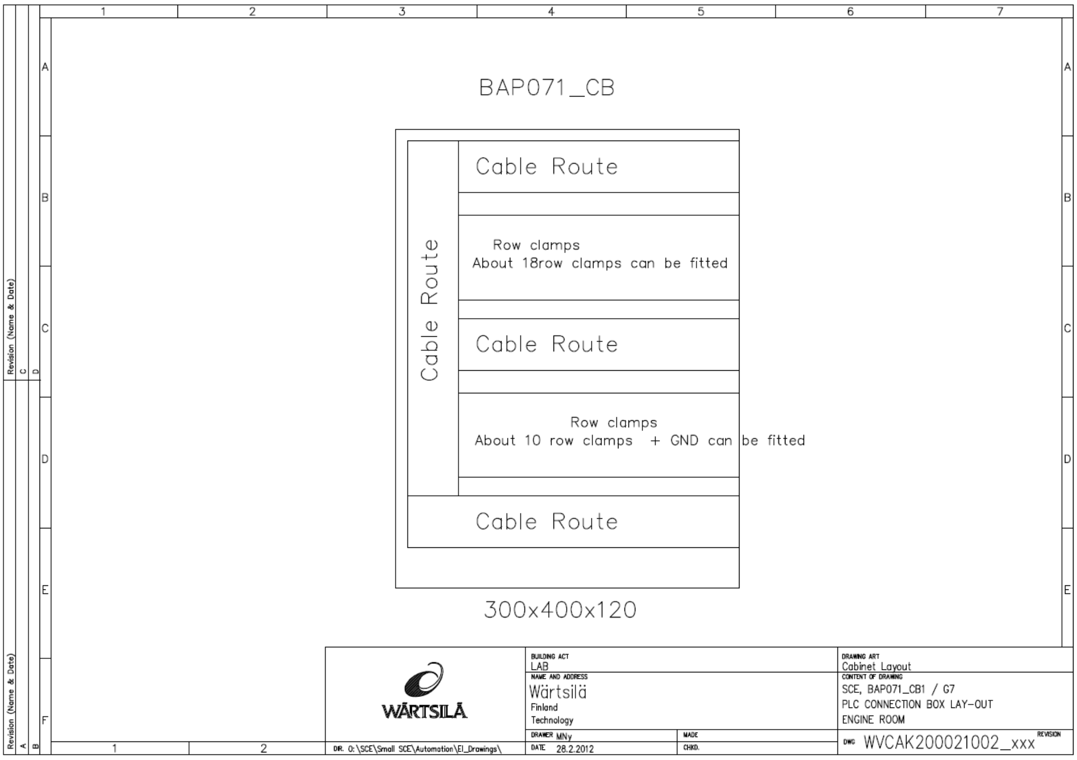

Figure 21. One of the CBs.

4.7.4 Other engine control systems

At the same time as drawing the layout pictures for the PLC cabinets, a layout picture of the engine control cabinet (SCX071) was drawn. In this cabinet the Unic system, the dSPACE system and the power supplies will be located. This cabinet will be located next to the main PLC cabinet and have a size of 800x2000x500 mm (width, height, and depth), which is as large as one of the PLC cabinets. The layout picture can be seen below in *Figure 22* and is quite similar to the PLC layouts.

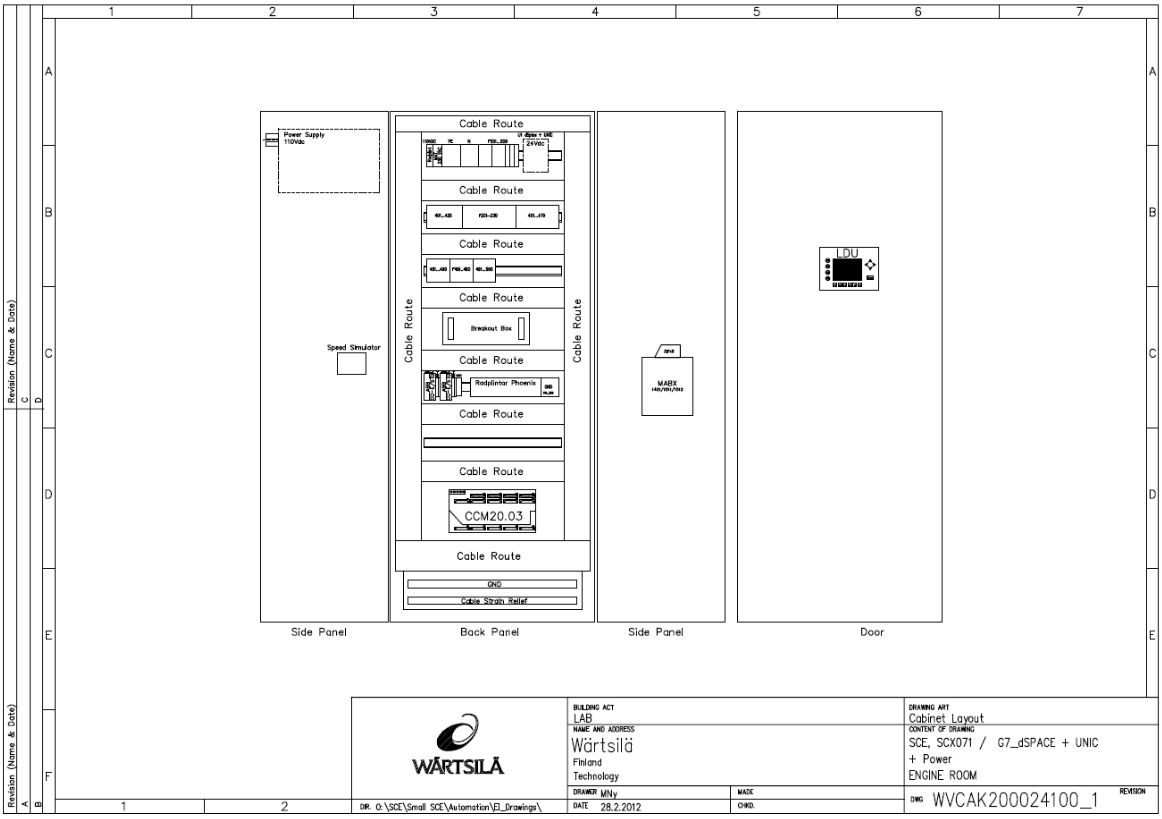

Figure 22. The Engine Control cabinet SCX071.

Except for this engine control cabinet, a network cabinet (BEY071) will also belong to the engine control system. In this cabinet the Morphee 2 computer and a fast measurement system (similar to the Osiris system) will be located. This cabinet was decided to be located in the Emission measurement room next to the test cell.

4.7.5 Order of the cabinets

The cabinets described in the previous chapters will be built in the Wärtsilä engine laboratory. To be able to start the building process, parts needed to be ordered. The only manufacturer that was considered at this stage was Rittal, since Wärtsilä has good agreements with Rittal and the previously used Rittal cabinets have worked to great satisfaction. Rittal has one disadvantage and that is the comprehensive procedure for the buyer, when making an order. All the different parts have to be checked so that they fit together. Rittal has many kinds of cabinets, accessories and cabinet entrails. This process was therefore done and the result was an order list, which can be seen in appendix 5. In the order, parts for all the automation cabinets (BAP071, BAP072, CBs, SCX071 and BEY071) are included. The parts for the BEY071 are a little different than those for the other cabinets, since BEY071 will have sides that can be opened and 19 ” rack entrails for mounting of the different components inside the cabinet.

5 Results

As a result of this evaluation a functional plan of the PLC architecture to the new test cell was made. This plan was achieved by evaluating the existing engine control system of SCE Mono and based on the evaluation, some concrete improvement proposals were made. The plan concentrates on the PLC part of the engine control system, but a few plans have been made of the other systems as well, e.g. a layout picture of the engine control cabinet.

To get a functional plan several small investigations were made. One of these was to investigate which PLC family to use in the new test cell. To determine the PLC family, the amount of I/O signals that will be located in the new test cell was estimated. A comparison between the Modicon PLC families and a cost calculation were also made. A more accurate estimation of the I/O amount was done after some of the PI schematics had arrived. Based on the new estimation a draft of where the I/O amount will be placed in the new test cell was done. This allowed the planning of the new PLC system to proceed and the amount and location of the PLCs cabinets could be decided on. It was decided that the main PLC cabinet would be located near the engine, because the largest I/O amount would be on and around the engine. A draft of where the cable routes were going to be located was made. This draft was based on the previous draft of the signal amount.

A comparison of the I/O amount between the upcoming test cell and the I/O amount in the SCE Mono test cell was done. The comparison allowed the size of the upcoming PLC cabinets to be decided on. Layout drawings of the different PLC cabinets were done and parts for the cabinets were ordered.

The thesis has mainly concentrated on decreasing the cable consumption and making a better order in the upcoming PLC cabinets. The improvement proposals will therefore save the cable consumption, e.g. the extended use of CBs is of such kind. Some other proposals were made which will improve the cable routes, the cabinet layouts, the PLC program and the total control system layout. The improvements will result in better expansion possibilities, service abilities and troubleshooting, and keep the total component costs down. Concrete results that can be seen with this thesis are layout drawings of several cabinets as well as the PLC comparison, the network layouts, a draft of the location of the I/O amount, a draft of the cable routes and an order of parts for the different cabinets.

6 Conclusion

The thesis work has been demanding to some degree, since the project has changed during the time of working. The work has mainly been about getting an understanding of the existing engine control system, about searching for information of all the parts in the control system and about figuring out how to implement a similar system into the new small SCE. If time had allowed it, also the differences between the Modicon Premium and the Modicon Quantum software could have been tested. This would have given a better understanding of the changes that have to be made before a program can be transferred from a Premium PLC to a Quantum PLC. However, since the project had to proceed and drawings had to be made, there wasn't enough time for that kind of research.

In total the goals of the thesis work were reached and as it looks at the moment, the planned layout will be used in the new test cell. This thesis has also contributed to the planning of the new engine control system for the small SCE, since some investigations had to be made before the project could proceed. The extended use of CBs also seem to be to a great advantage, since the project struggles with delays at the moment and parts of the engine system can therefore be built in advance. E.g. the lubrication oil module can be built outside the test cell, with all its transmitters and even valves can be connected to a connection box. This will lead to a shorter time range of the installation, when only a trunk cable needs to be equipped after the module is moved into the engine test cell, and the project can still be finalized in time.

The thesis has also contributed to giving me a better understanding of control systems for Wärtsilä engines, which is needed to proceed with the designing of the electrical drawings for the small SCE and the knowledge will also be needed in other future work tasks for the SCE.

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Appendices

1.	Illustration of the Measurement Network of SCE Mono.	1 page.
2.	Illustration of the Control Network of SCE Mono.	1 page.
3.	Comparison of Modicon PLC Families	1 page.
4.	Selection of Power Supplies for the PLCs	3 pages.
5.	The Order of the Cabinets	2 pages.

Illustration of the Control Network.

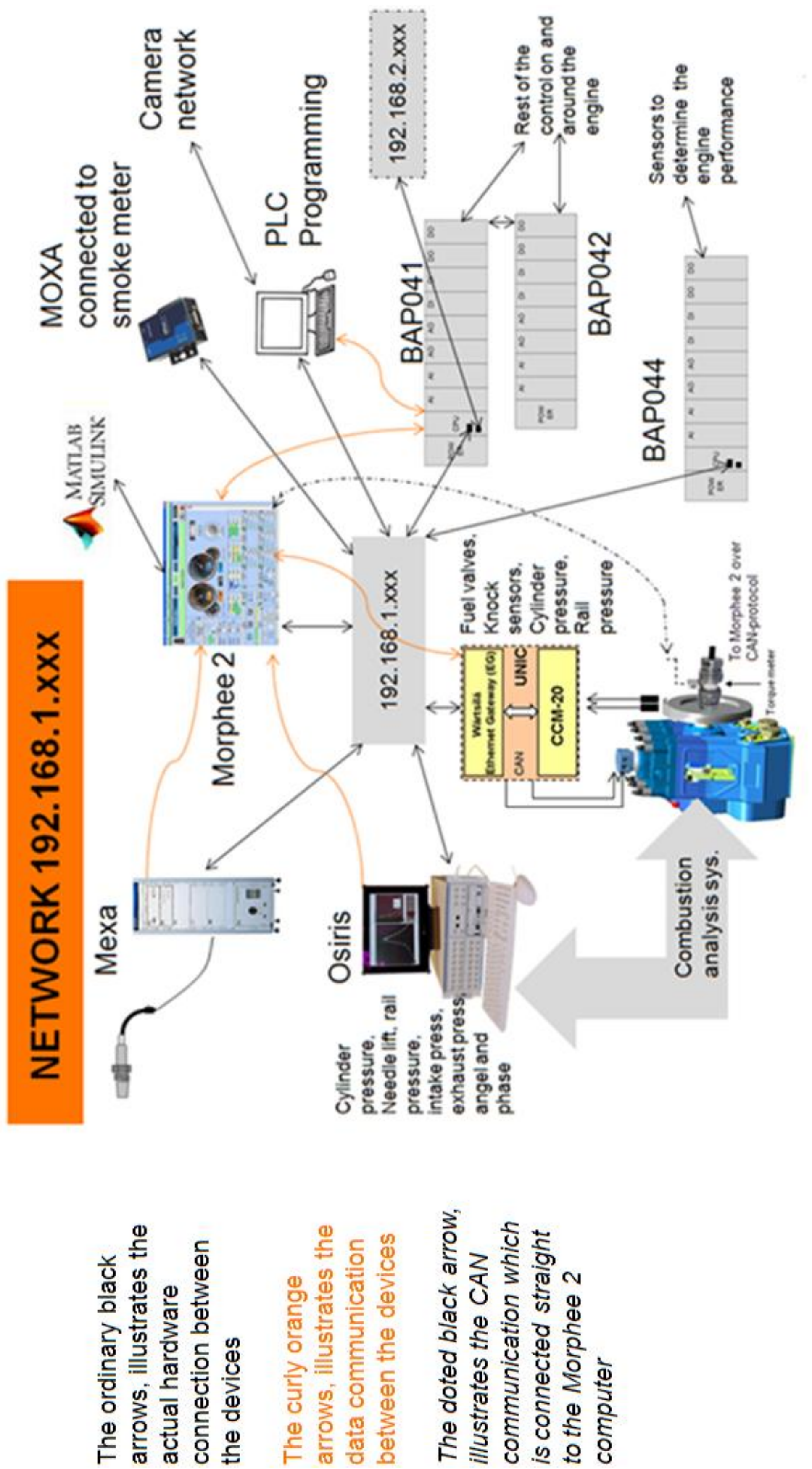
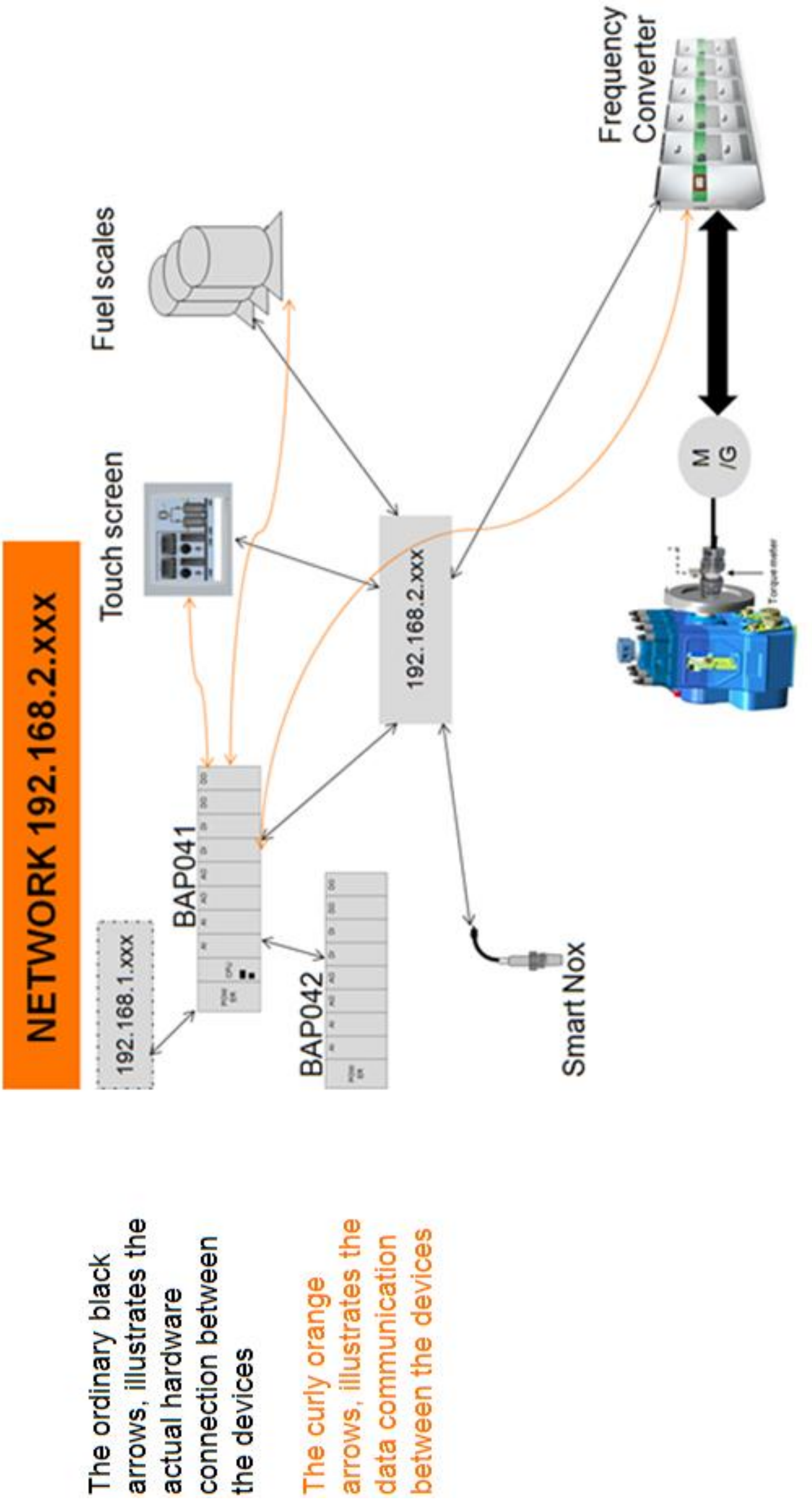


Illustration of the Measurement Network.



Comparison of Modicon PLC Families

Comparison of Modicon PLC families

	Quantum	Premium	M340
Languages	5 IEC languages as standard: LD, ST, FBD, SFC, IL	5 IEC languages as standard: LD, ST, FBD, SFC, IL	5 IEC languages as standard: LD, ST, FBD, SFC, IL
Memory	2,5MB program, 800k data and config without PCMCIA, with 7Mb program 3Mb data 8Mb file storage	2MB program and data, with PCMCIA module 7MB program and 2MB data	3584 KB program 256K data, SD-card for backup file storage, web server
CPU speed	45 ns per instruction (10,07Kinst/min 10,28 if 100% boolean)	45 ns per instruction (14Kinst/min 20,6 if 100% boolean)	250 ns per instruction (6,4Kinst/min 8,1if 100% boolean)
BUS max cabel length	4572m remote I/0 (15km with fiber repeater), 457m distributed I/O	Witouh remote module 100m, with remote modules 2x350m	30m
Number of racks	64x(16) + 62x(16) Remote I/O(coaxial)+ 63x(4) Distributed I/O(Twisted pair)	Up to 16 with 4, 6, 8 slots or 8 with 12 slots	Up to 4(with 4, 6, 8 or 12 slots)
Max nr of slots	27 local + 992 remote + 252 distributed	128	48
DI/O	1024 inputs/1024 outputs Local + 31 744 inputs/31 744 outputs Remote + 7840 inputs/7840 outputs distributed	2040channels (modules with 8, 16, 32 or 64 channels)	1024 channels (modules with 8, 16, 32 or 64 channels)
AI/O	64 inputs/64 outputs Local + 1984 inputs/1984 outputs Remote + 500 inputs/500 outputs distributed	512channels (modules with 2, 4, 6 or 8 channels)	256 channels (modules with 2, 4, 6 or 8 channels)
Distributed I/O	992 remote units + 252 distributed I/Os	All backpanels can be configured as a remote unit	Limited depending on the type of medium: on CANopen bus (63 devices), on Ethernet Modbus/TCP network via network module (63 devices with I/O Scanning function), on Modbus link (32 devices)
No of channels for Counter, motion control and serial link	5 + 2 + 16 + 1	64 max	36 max
Memorycard	PCMCIA modules 7 MB + 8 MB	PCMCIA module 7MB	8 MB backup as standard, 8 or 128MB file storage

Selection of Power Supplies for the PLCs

PLC Power Supply Selection

Back Panel 1:

		Consumption in mA			Total consumption in mA	
Description	Type	5 V	24 V	Amount	5 V	24 V
Analog in	TSX AEY 810	475		*0*	0	0
Analog out	TSX ASY 410	900		*5*	4500	0
Digital in	TSX DEY 32D2K	135	160	*1*	135	160
Digital out	TSX DSY 32T2K	140		*1*	140	0
Unity CPU unit	TSX P576634M	1880		*1*	1880	0
Ethernet unit	TSX ETY 4103/5103	360		*1*	360	0
				Total I (mA):	7015	160
				Total P (mW)	35075	800

Back Panel 2:

		Consumption in mA			Total consumption in mA	
Description	Type	5 V	24 V	Amount	5 V	24 V
Analog in	TSX AEY 810	475		*10*	4750	0
Analog out	TSX ASY 410	900		*0*	0	0
Digital in	TSX DEY 32D2K	135	160	*0*	0	0
Digital out	TSX DSY 32T2K	140		*0*	0	0
Unity CPU unit	TSX P576634M	1880		*0*	0	0
Ethernet unit	TSX ETY 4103/5103	360		*0*	0	0
				Total I (mA):	4750	0
				Total P (mW)	23750	0

Back Panel 3:

		Consumption in mA			Total consumption in mA	
Description	Type	5 V	24 V	Amount	5 V	24 V
Analog in	TSX AEY 810	475		*0*	0	0
Analog out	TSX ASY 410	900		*3*	2700	0
Digital in	TSX DEY 32D2K	135	160	*2*	270	320
Digital out	TSX DSY 32T2K	140		*2*	280	0
Unity CPU unit	TSX P576634M	1880		*0*	0	0
Ethernet unit	TSX ETY 4103/5103	360		*0*	0	0
				Total I (mA):	3250	320
				Total P (mW)	16250	1600

Back Panel 4:

		Consumption in mA			Total consumption in mA	
Description	Type	5 V	24 V	Amount	5 V	24 V
Analog in	TSX AEY 810	475		*10*	4750	0
Analog out	TSX ASY 410	900		*0*	0	0
Digital in	TSX DEY 32D2K	135	160	*0*	0	0
Digital out	TSX DSY 32T2K	140		*0*	0	0
Unity CPU unit	TSX P576634M	1880		*0*	0	0
Ethernet unit	TSX ETY 4103/5103	360		*0*	0	0
				Total I (mA):	4750	0
				Total P (mW)	23750	0

Back Panel 5:

		Consumption in mA			Total consumption in mA	
Description	Type	5 V	24 V	Amount	5 V	24 V
Analog in	TSX AEY 810	475		*3*	1425	0
Analog out	TSX ASY 410	900		*3*	2700	0
Digital in	TSX DEY 32D2K	135	160	*1*	135	160
Digital out	TSX DSY 32T2K	140		*1*	140	0
Unity CPU unit	TSX P576634M	1880		*1*	1880	0
Ethernet unit	TSX ETY 4103/5103	360		*0*	0	0
				Total I (mA):	6280	160
				Total P (mW)	31400	800

Worst Case Scenario

		Consumption in mA			Total consumption in mA	
Description	Type	5 V	24 V	Amount	5 V	24 V
Analog in	TSX AEY 810	475		*0*	0	0
Analog out	TSX ASY 410	900		*8*	7200	0
Digital in	TSX DEY 32D2K	135	160	*0*	0	0
Digital out	TSX DSY 32T2K	140		*0*	0	0
Unity CPU unit	TSX P576634M	1880		*1*	1880	0
Ethernet unit	TSX ETY 4103/5103	360		*0*	0	0
				Total I (mA):	9080	0
				Total P (mW)	45400	0

Module selector
(can be photocopied)

Modicon® Premium™ automation platform
TSX™ PSY Power Supply

The power required to supply each TSX™ RKY rack depends on the type and number of modules installed. It is therefore necessary to create a power consumption table for each rack in order to define the most suitable TSX™ PSY power supply module for each rack.
The table below can be used to calculate the consumption on the three different voltages to be supplied (⎓ 5 V, ⎓ 24 V, ⎓ 24 VR).

Procedure :

- Check and choose a power supply module corresponding to the power supplies available for the 3 voltages.
- Check that the total power absorbed on these three voltages does not exceed the overall power of the power supply module.
- Values to be entered according to the type of Modicon® Premium™ PLC configuration.

Rack n°	Reference	Format S : standard D : double	Number	Consumption in mA *(1)* Voltage ⎓ 5 V Module	Total	Voltage ⎓ 24 VR Module	Total	Voltage ⎓ 24 V Module	Total
Unity™ processors with memory extension card	**TSX™ P57 0244M**	S		850					
	TSX P57 104M	S		850					
	TSX P57 1634M	D		1650					
	TSX P57 154M	S		930					
	TSX P57 204M	D		850					
	TSX P57 2634M	D		1650					
	TSX P57 254M	D		930					
	TSX™ H5724M	D		1880					
	TSX P57 304M	D		1100					
	TSX P57 3634M	D		1900					
	TSX P57 354M	D		1180					
	TSX P57 454M	D		1680					
	TSX P57 4634M	D		1880					
	TSX H5744M			1880					
	TSX P57 554M	D		1680					
	TSX P57 5634M	D		1680					
	TSX P57 6634M	D		1880					
PL7™ processors with memory extension card	**TSX P57 103M**	S		440					
	TSX P57 153M	S		8530					
	TSX P57 203M	D		750					
	TSX P57 2623M	D		1110					
	TSX P57 253M	D		820					
	TSX P57 2823M	D		1180					
	TSX P57 303AM	D		1000					
	TSX P57 3623AM	D		1360					
	TSX P57 353AM	D		1060					
	TSX P57 353LAM	S		1650					
	TSX P57 453AM	D		1080					
	TSX P57 4823AM	D		1440					
Discrete I/O	**TSX™ DEY 08D2**	S		55				80	
	TSX DEY 16A2	S		80					
	TSX DEY 16A3	S		80					
	TSX DEY 16A4	S		80					
	TSX DEY 16A5	S		80					
	TSX DEY 16D2	S		80				135	
	TSX DEY 16D3	S		80				135	
	TSX DEY 16FK	S		250				75	
	TSX DEY 32D2K	S		135				160	
	TSX DEY 32D3K	S		140				275	
	TSX DEY 64D2K	S		155				315	
	TSX™ DSY 08R4D	S		55		80			
	TSX DSY 08R5	S		55		70			
	TSX DSY 08R5A	S		55		80			
	TSX DSY 08S5	S		125					
	TSX DSY 08T2	S		55					
	TSY DSY 08T22	S		55					
	TSX DSY 08T31	S		55					
	TSX DSY 16R5	S		80		135			
	TSX DSY 16S4	S		220					
	TSX DSY 16S5	S		220					
	TSX DSY 16T2	S		80					
	TSX DSY 16T3	S		80					
	TSX DSY 32T2K	S		140					
	TSX DSY 64T2K	S		155					
	TSX™ DMY 28FK	S		300				75	
	TSX DMY 28RFK	S		300				75	
Bus X remote	**TSX™ REY 200**	S		500					
Total (carry over to page 9/7)		Current (mA)							

Module selector
(can be photocopied)

Modicon® Premium™ automation platform
TSX™ PSY Power Supply

Rack n°

	Reference	Format S : standard D : double	Number	Consumption (mA) (1) Voltage ⎓ 5 V Module	 Total	 Voltage ⎓ 24 VR Module	 Total	 Voltage ⎓ 24 V Module	 Total
Carried forward		Current (mA)							
Analog I/O	**TSX™ AEY 414**	S		660					
	TSX AEY 420	S		500					
	TSX AEY 800	S		270					
	TSX AEY 810	S		475					
	TSX AEY 1600	S		270					
	TSX AEY 1614	S		300					
	TSX™ ASY 410	S		900					
	TSX ASY 800 (2)	S		200		300			
Safety	**TSX™ PAY 262**	S		150				200	
	TSX PAY 282	S		150				200	
Counting, motion control and weighing	**TSX™ CTY 2A**	S		280				30	
	TSX CTY 4A	S		330				36	
	TSX CTY 2C	S		850				15	
	TSX™ CCY 1128	S		660				15	
	TSX™ CAY 21	S		1100				15	
	TSX CAY 41	D		1500				30	
	TSX CAY 22	S		1100				15	
	TSX CAY 42	D		1500				30	
	TSX CAY 33	D		1500				30	
	TSX™ CFY 11	S		510				50	
	TSX CFY 21	S		650				100	
	TSX™ CSY 84/164	D		1800					
	TSX™ ISPY101	S		150		145			
Communication	**TSX™ ETY 110 WS** (3)	S		800					
	TSX ETY 110 WS (4)	S		1200					
	TSX ETY 4103/5103	S		360					
	TSX™ IBY 100	S		500					
	TSX™ PBY 100	S		400					
	TSX™ SAY 1000	S		100					
	TSX™ SCY 11601	S		350					
	TSX SCY 21601	S		350					
	TSX™ SCP 111	–		140					
	TSX SCP 112	–		120					
	TSX SCP 114	–		150					
	TSX™ FPP 10	–		330					
	TSX FPP 20	–		330					
	TSX™ MBP 100	–		220					
	TSX™ CPP 110			60					
	TSX™ P ACC 01	–		150					
Terminal	**T FTX 117 ADJ02**	–		310					

Consumption per voltage

	⎓ 5 V		⎓ 24 VR		⎓ 24 V		Total of the 3 powers
Total current (mA)							
	x 5 V		x 24 VR		x 24 V		
Power (mW)		+		+		=	
	≤		≤		≤		≤

				Power available in mW			Overall
Choice of power supply	**TSX™ PSY 1610**	S	⎓ 24 V non isolated	15 000	15 000	–	30 000
	TSX PSY 2600	S	∿ 100…240 V	25 000	15 000	12 000	26 000
	TSX PSY 3610	D	⎓ 24 V non isolated	35 000	19 000	–	50 000
	TSX PSY 5520	D	⎓ 24…48 V isolated	35 000	19 000	–	50 000
	TSX PSY 5500	D	∿ 100…120 V ∿ 200…240 V	35 000	19 000	19 000	50 000
	TSX PSY 8500	D	∿ 100…120 V ∿ 200…240 V	75 000	–	38 000	77 000 (5)

(1) Typical value given for 100% of inputs or outputs at state 1.
(2) If using an external ⎓ 24 V sensor power supply, the consumption on the ⎓ 24 V voltage should not be included.
(3) Without remote power supply (RJ45).
(4) With remote power supply (AUI).
(5) 77,000 mW at 60 °C, 85,000 mW at 55 °C or 100,000 mW at 55 °C when using **TSX™ FAN ••P** *fan modules.*

Appendix 5
(1/2)

The Order of the Cabinets

Amount	Model No.	Designation	Size	Customs number
10	EB 1556.500	E Box painted RAL 7035	300 mm x 400 mm x 120 mm	94032080
5	TS 8805.500	Top enclosure system painted RAL 7035, with mounting plate single-door	800 mm x 2.000 mm x 500 mm	94032080
3	TS 8105.235	Side panels, pair, for 2000 X 500 mm RAL	0 mm x 2.000 mm x 500 mm	94039010
5	TS 8602.800	Base/plinth components f+r, RAL 7022 WxH 800 x 200 mm	800 mm x 200 mm x 0 mm	94039010
3	TS 8602.050	Base/plinth trim side, 200 mm high	0 mm x 200 mm x 500 mm	94039010
2	TS 8800.490	Baying connector, external for TS/TS	6/box	83024900
5	TS 8612.150	Punched section with mounting flange outer mounting level for 500mm horizontal	4/box	73269098
5	TS 8612.250	Punched rail 18x38mm for WxD	4/box	73269098
2	TS 7828.081	Cable clamp rails inner mounting level	4/box	73269098
2	TS 7828.082	Cable clamp rails outer mounting level	4/box	73269098
1	TS 8806.500	Top enclosure system painted RAL 7035, with mounting plate single-door	800 mm x 2.000 mm x 600 mm	94032080
1	TS 8106.235	Side panels, pair, for 2000 X 600 mm RAL	0 mm x 2.000 mm x 600 mm	94039010
1	TS 8602.800	Base/plinth components f+r, RAL 7022 WxH 800 x 200 mm	800 mm x 200 mm x 0 mm	94039010
1	TS 8602.060	Base/plinth trim side, 200 mm high	0 mm x 200 mm x 600 mm	94039010
2	DK 7827.600	DK-TS depth stay	800 mm x 600 mm 4/box	73269098
1	DK 7827.200	DK-TS mounting angle 42 U	2/box	73269098
1	DK 7827.100	DK-TS mounting angle 20 U	2/box	73269098
3	DK 7492.060	Heavy-duty slide rail	561 mm 2/box	73269098
1	TS 8612.060	Punched section with mounting flange inner mounting level for 600mm horizontal	600 mm x 600 mm 4/box	73269098
1	TS 8800.130	Support strips for 600mm frame	20/box	73269098
1	TS 8800.110	Hinges for TS side panel, screw-fastened, sheet steel TS side panel, asymmetrical	6/box	83024900
1	TS 8800.190	180° hinges	4/box	83021000
1	SZ 2365.000	Rail mounting bracket, flat	20/box	73269098
1	SZ 2366.000	Rail mounting bracket, inclined	20/box	73269098
5	SZ 4138.190	Standard light with door-operated switch 18 W/ 230 V	682 mm x	94054095
5	SZ 4315.150	Connection cable, UL 3000 mm, socket	3m	85444290
6	TS 8800.080	Cable entry plate, 8 cut-outs	2/box	73269098
2	PS 4316.000	Cable entry grommet 8x13mm	25/box	39269097
4	PS 4317.000	Cable entry grommet 3x21mm	25/box	39269097
4	SZ 2364.000	PE busbar 699 mm long	1/box	74199990
4	DK 7113.000	Earth rail, horizontal for TS 455 mm	1/box	74199990
1	SZ 2413.550	EMC shield bus W=550 mm	550 mm x 1/box	73269098
4	SZ 2514.000	Plastic wiring plan pockets, A4 Portrait	1/box	39269097

2013-03-27 Rittal

Kassalle | Tyhjennä ostoskori | Sulje ikkuna

Tuotenumero	Tuotekuvaus	Määrä	Hinta €
1556500 *	EB-kotelo	10	
8805500 *	Kaappi TS 800x2000x500 RAL7035	5	
8105235 *	Sivuseinät TS 2000x500 RAL7035	3	
8602800 *	Jalustan etu/taka 800x200	6	
8602050 *	Jalustan sivut 200x500	3	
4138190 *	Vakiovalaisin ovikyt. 18w 230V/50Hz	5	
4315150	Liitäntäjohto virransyötölle, UL	5	
8800080 *	Kaapeliläpivientilevy lev. 800 2kpl	6	
4316000 *	Kaapeliläpivienti 8/13 25kpl	2	
4317000 *	Kaapeliläpivienti 3/21 25kpl	4	
8800490 *	Ulkopuolinen rivityspala 6 kpl	2	
8612150 *	Asennuskisko ulompi 500 4 kpl	5	
8612250 *	Asennuskisko 18x38 ls 500 4kpl	5	
7828081	Vedonpoistokiskot sis. TS 800 4kpl	2	
7828082	Vedonpoistokiskot ulo. TS 800 4kpl	2	
8806500 *	Kaappi 800x2000x600	1	
8106235 *	Sivuseinät TS 2000x600 RAL7035	1	
8602060 *	Jalustan sivut 200x600	1	
7827600 *	As.sarja profiilikiskoil. TS8 4kpl	2	
7827200 *	19" profiilikisko 42HE TS 2kpl	1	
7827100 *	19" profiilikisko 20HE TS 2kpl	1	
7492060 *	Liukukiskot läpimen.561mm vp=2	3	
8612060 *	Asennuskisko sisempi 600mm 4kp	1	
8800130	Asennuskisko sis.taso l/s=600 20kpl	1	
8800110	Saranat sivuseinälle,ruuvikiin 6kpl	1	
8800190 *	Saranat 180 astetta RAL 7035 4kpl	1	
2364000 *	Maadoitusjohto-keräilykisko	4	
7113000 *	Maadoituskisko p=450 20 liitt.	4	
2413550	EMC maadoituskisko 550mm	1	
2514000 *	Kaaviotasku DIN A4 polystyrol	4	
2365000 *	Asennussanka matala 30mm 20kpl	1	
2366000 *	Asennussanka vino 47mm 20kpl	1	
*Löytyy varastosta		Summa:	